EDCS IN WASTEWATER: WHAT'S THE NEXT STEP?

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ABSTRACT

The fact that many known and suspected endocrine disrupting chemicals (EDCs) are being found at environmentally significant concentrations in the effluent of wastewater treatment plants (WWTPs) is receiving increasing attention in public and regulatory arenas. The public is concerned about the safety of consuming trace amounts of EDCs in drinking water, though the only confirmed negative effects from EDC exposure have involved wildlife health.

Ample research opportunity exists for the scientific community on this topic: most EDCs have not been identified and/or studied, analytical methods for many identified EDCs have yet to be developed, and the levels of toxicological significance or impact must be established. Additional work must also be done to determine the potential for (1) interactive toxicological effects in EDC mixtures and (2) the formation of undesirable byproducts through treatment. It is likely that the EPA will not consider regulating EDCs until more research has been completed.

Research shows that complete biodegradation of many chemicals of concern can be achieved with adequate SRT and/or HRT in the activated sludge system. When contaminants are persistent or if extremely low effluent concentrations are required, however, higher level removal technology may be needed. Several advanced technologies, such as activated carbon adsorption, ozonation, AOPs, and NF/RO, have successfully removed potential EDCs from water. Most of these technologies, however, are expensive to implement and to operate. Optimization of the activated sludge process could be a less costly option. Issues of by-product formation and EDC additive effects will be important considerations in the design of any treatment strategy.

Long-term facility planning should allow for design flexibility to accommodate possible future EDC regulations. Potential treatment strategies can be incorporated into existing layouts, and room should be left for new equipment. Process selection criteria such as space requirements, byproduct issues, and compatibility with existing facilities must be considered. Planning should favor processes and management strategies that will address not only the concern for EDCs, but other water quality goals as well, so that capital expenditures will cover more than the single, somewhat unclear EDC issue.

Based on current information, it seems logical that a major focus for EDC and PPCP removal should be at the WWTP. Removal of these pollutants from WWTP effluent may solve much of the apparent endocrine disruption problem in the water environment in addition to providing a cleaner source for drinking water.

KEYWORDS

Wastewater treatment, endocrine disruption, pharmaceuticals, personal care products.

INTRODUCTION

The endocrine system is one of the two main regulatory systems in humans and other organisms. It consists of glands that secrete hormones which are transported in the bloodstream to different parts of the body. These hormones act to control body functions, including reproduction, growth, and development.

Simply stated, an endocrine disrupter is an exogenous substance that changes the function of the endocrine system, affecting the way an organism or its progeny reproduces, grows, or develops. Though most research to date has focused on the disruptive effects on reproduction and development, more recent efforts are examining the effects of disruption on thyroid function and the immune system (McCann, 2004).

Endocrine disrupting chemicals (EDCs) and pharmaceutical and personal care products (PPCPs) are ubiquitous in the environment because of their seemingly endless number of uses and origins in residential, industrial, and agricultural applications. EDCs are derived from both anthropogenic and natural sources; the USEPA is in the process of defining exactly what an EDC is, and those chemicals that meet the toxicity definition will be classified as such in the coming years. The term PPCPs refers to chemicals that enter the environment through use of human and veterinary pharmaceuticals and myriad other products such as antibiotics, analgesics, fragrances, sunscreen, mouthwash, bug spray, and cosmetics. Some PPCPs are suspected of being EDCs, but the terms are not interchangeable and the toxicity concerns associated with the two different groups can be very different. Though the potential hazards associated with some EDCs and PPCPs, such as DDT and DES, have been known for decades, the environmental and health effects of these chemicals in general are only beginning to gain worldwide attention in public and regulatory arenas. Hundreds of compounds are now listed as suspected EDCs; some of these, along with their primary sources, are presented in Figure 1.

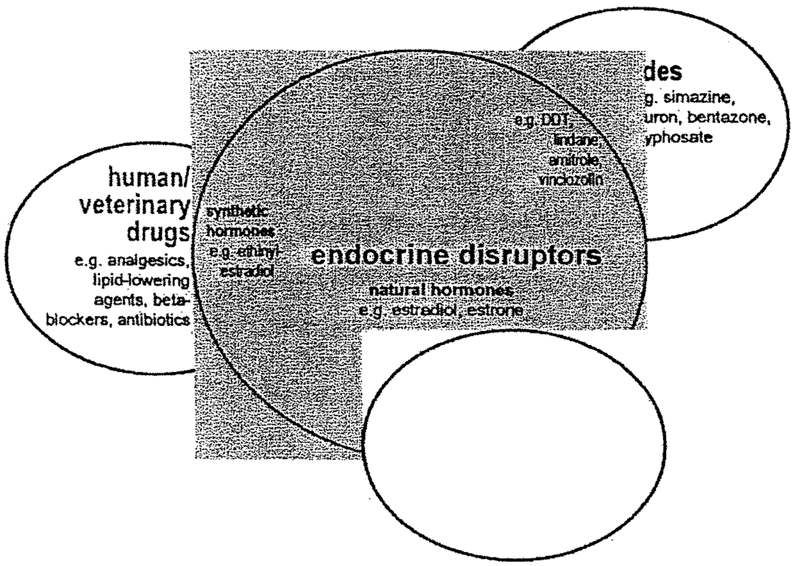

Figure 1. Example of Some EDCs from Various Sources.

There are various pathways by which organisms can be exposed to EDCs and PPCPs; of these, contamination of the water cycle is especially important. EDCs and PPCPs enter the water environment largely through treated wastewater effluent and inputs to water bodies from agricultural or feedlot operations. Agricultural inputs are significant in some areas, and controlling them will be quite a challenge for many reasons. Wastewater treatment plant (WWTP) effluent can be a source for various types and amounts of EDCs and PPCPs, depending on service area characteristics, because most of the WWTPs in service today have not been designed to remove them. Thus, some micropollutants will not be completely degraded or removed through the wastewater treatment process. Aquatic organisms and other wildlife are exposed to EDCs and PPCPs through direct contact in the water environment. Numerous researchers in various countries have reported on the negative effects of WWTP effluent on the reproductive systems of aquatic organisms living in the vicinity of WWTP outfalls. For example, sexual disruption of fish has been linked to estrogenic substances in treated WWTP effluent (Purdom et al., 1994; Jobling et al., 1998; Pickering and Sumpter, 2003). Such effects on wildlife have led to concerns about adverse health consequences in humans, as it is possible that humans can be exposed to EDCs and PPCPs through their drinking water and food.

STATE OF CURRENT EDC KNOWLEDGE BASE

Regulatory and Research Efforts

There is ample research opportunity for the scientific community on the topic of EDCs: most EDCs have not been identified and/or studied, analytical methods for many of the identified EDCs have yet to be developed, and the levels of toxicological significance or impact must be established. Beyond identifying EDCs, additional work must also be done to determine the potential for (1) interactive toxicological effects in EDC mixtures and (2) formation of treatment byproducts that are more dangerous than the parent compounds that were targeted for removal. The U. S. Environmental Protection Agency (EPA) is not likely to consider regulating EDCs until more research has been completed, though long-term facility planning should take into account that some EDCs may be regulated in the future.

Through the Safe Drinking Water Act (SDWA), the EPA currently regulates a number of possible EDCs such as atrazine, chlordane, DDT, dioxin, cadmium, lead, and mercury. But the maximum contaminant levels for these chemicals are defined by their toxic/cancer-causing effects rather than endocrine disruption. EDCs have not been mentioned specifically in U.S. legislation until 1995, when amendments to the SDWA and the Food Quality Protection Act mandated screening of all chemicals and formulations for potential endocrine activity prior to their use or manufacture where they could cause contamination of drinking water or food. To develop a comprehensive screening program, the EPA established the Endocrine Disruptor Screening and Testing Advisory Committee (EDSTAC). In its final report in 1998, the EDSTAC recommended consideration of: (1) both human and wildlife effects; (2) examination of estrogen, androgen, and thyroid endpoints; (3) a plan for assessing an estimated 87,000 chemicals; and (4) evaluation of six specific classes of mixtures in addition to discrete chemicals. In 2001, the Endocrine Disruptor Methods Validation Subcommittee (EDMVS) was formed to evaluate and validate methods for standardization of EDC testing. Once this work is completed, we should be able to definitively identify which chemicals are indeed EDCs (Snyder et al., 2003b).

In 1999 and 2000, the United States Geological Survey (USGS) sampled 139 streams across 30 states in the U.S. as the first nationwide reconnaissance of the occurrence of PPCPs and potential EDCs. The survey included sampling for 95 constituents from a wide variety of origins, and found that contamination was generally prevalent and widespread (Koplin et al., 2002). While the authors noted that contaminant concentrations tended to be low and rarely exceeded guidelines for drinking water quality, few federal guidelines or regulations exist concerning EDC or PPCP contamination of our drinking or natural waters. Additional studies must be conducted at relevant concentrations of these substances to identify their toxicologically significant levels and to establish reasonable regulations, if any are required. The state of California is considering regulations for EDCs and PPCPs in indirect potable reuse applications, prompting some practitioners of indirect potable reuse to establish monitoring programs now. Since California is a leader in water reuse, this move may stimulate similar actions in other programs around the world.

The EPA is establishing a reference dose for perchlorate, which may become the first pollutant to be regulated in the U.S. for endocrine disrupting toxicity (Snyder, 2003). Several European countries and Japan, however, already have begun phasing out or limiting the use of a few specific EDCs. Besides the U.S., Europe, and Japan, Australia and Canada also see EDC and PPCP contamination as a priority issue and have research programs in place. Both the European Union (EU) and the United Nations (UN) have launched plans for elimination of priority hazardous substances (European Commission Report, 2001; Stockholm Convention, 2001). The current U.S. administration has pledged support of the UN effort.

In addition, a model has been developed to estimate the concentrations of active pharmaceutical ingredients (API) in U. S. surface waters that result from human consumption. Using a mass balance approach, the P*h*ATE (Pharmaceutical Assessment and Transport Evaluation) model predicted the environmental concentrations of several APIs and the results were compared with measured values at 40 locations. In general, the P*h*ATE model was able to estimate concentrations to within a factor of ten of measured values, indicating that it may have value as a screening tool for estimating the presence of human pharmaceuticals in watersheds nationwide (Anderson et al., 2004).

Human and Wildlife Health Effects

Regarding the effect of EDCs on human health, it has been primarily fear of the unknown rather than fear of the known that has fueled widespread public concern. Excluding specific cases of "high dose response" exposure, results of studies involving population and health trends are inconsistent and do not establish an irrefutable link between low-level exposure to EDCs and adverse consequences to human health. It is the opinion of some scientists, such as Snyder (2003), that the amount of estrogenic chemicals in drinking water is not likely responsible for adverse human health effects because the estrogenic content in water is minute compared with the amount in foods. In addition, exposure to EDCs for humans is completely different from that for fish or other aquatic organisms, so the same response should not be expected. New findings released last year at the ECOHAZARD conference in Germany indicate that it is nearly certain that human exposure to EDCs through drinking water is not significant (McCann, 2004). The scientific community is far from consensus on the topic, though. The issue is far from closed, and scientists, along with environmental and industry groups, are likely to continue to debate it for years to come.

Research into the health effects of EDCs on wildlife is far from exhaustive, but there is more evidence linking EDCs with adverse impacts on wildlife health than on human health. Numerous studies over the past 70 years have demonstrated endocrine disruption in a variety of organisms, including gulls, marine gastropods, frogs, fish, and alligators, as a result of exposure to pesticides, steroids, surfactants, plasticizers, and other synthetic chemicals (Snyder et al., 2003b). New research indicates that there are over 200 species with known or suspected adverse reactions to endocrine disruptors (McCann, 2004).

Identifying the Most Hazardous Chemicals

While debate over what actually defines an EDC is still ongoing, it is generally accepted that the three main classes of endocrine disruption endpoints are estrogenic (natural estrogen blocked or mimicked), androgenic (natural testosterone blocked or mimicked), and thyroidal (thyroid function affected directly or indirectly). The majority of research to date has focused on estrogenic compounds, though disruption of androgen or thyroid function may prove to be of equal or greater importance biologically (Snyder et al., 2003b). Currently, the scientific community is drawing conclusions about the relative hazards of potential EDCs based on collective results of batch, pilot, and full-scale experiments and studies from around the world. In an excellent summary of research involving fate of EDCs and PPCPs in WWTPs, Johnson and Sumpter (2001) conclude that estrone (E1) and estradiol (E2) would be the EDCs of greatest concern based on in vitro potency, while ethinylestradiol (EE2) and the alkylphenols (OP and NP would be more important based on the more relevant *in vivo* potencies. They state that this latter group could account for as much as 90% of the estrogenicity in a typical WWTP effluent. Discharge concentrations, magnitude of in-stream dilution, and type(s) of species involved are also important factors in considering the impact of the estrogens. It is important to remember, though, that much of the research to date has focused on estrogens, since that is where most wildlife effects have been observed, so conclusions may change as our data base broadens. It is also likely that as research in this area proceeds and analytical technologies advance, scientists will only discover more hazardous chemicals and/or degradation products at even lower concentrations, so this list may prove to be constantly evolving.

Pinpointing the effects of EDC exposure in humans and wildlife is very difficult, since environmental exposure is at very low levels and the perceived effects of endocrine disruption can be subtle and their manifestation may take years. Confusing the matter is the fact that research centers in different countries may use different EDC testing and screening procedures, so they may not agree upon the endocrine disrupting properties of a given substance found in the environment. And without unbiased internationally agreed-upon testing procedures, any unified international response to EDC contamination may be difficult (McCann, 2004).

EFFECT OF WASTEWATER TREATMENT ON EDCS

General

Though WWTPs have been shown to remove substantial amounts of many EDCs from the influent wastewater, low concentrations in the effluent may still lead to in-stream concentrations that are of significance to fish and other aquatic species (Johnson and Sumpter, 2001). Levels of toxicological significance are still being investigated, though research has shown estrogenic effects in rainbow trout at E2 and EE2 concentrations as low as 10 and 0.5 ng/L, respectively (Purdom et al., 1994). The actual concentration seen by aquatic organisms depends on the quantity of water available for dilution in the receiving stream. In population-dense, water-poor areas, high pollutant concentrations in the final effluent are of obvious concern.

Depending on their physicochemical properties, EDCs may be removed through adsorption, biological degradation and transformation, chemical degradation, or volatilization (Birkett and Lester, 2003). Findings reported in the literature indicate that removal efficiency through wastewater treatment varies considerably depending on the type of compound and removal process. The latest research into WWTP reduction capabilities indicates that "endocrine active substances" in the influent from primarily domestic sources were more susceptible to breakdown and removal. With other types of contaminants, very little reduction may occur through the WWTP. If these more intractable chemicals must be removed, application of advanced wastewater treatment technologies like membranes or ozonation may be needed (McCann, 2004). Thus, the technology applied at any given plant must be based on a thorough understanding of wastewater constituents.

Table 1 is an example of general information that can be found in the literature concerning removal of some EDCs and PPCPs through various wastewater treatment processes. It is important to note that the removals are discussed in terms of percentages, since initial concentrations are not provided, it is impossible to know how realistic the removal rates are or what can be expected for effluent quality in a given situation, especially given the fact that some performance studies are done using influent spiked with high contaminant concentrations. This is important, since some compounds may affect the aquatic environment at very low concentrations, and must therefore be reduced to extremely low effluent concentrations through wastewater treatment.

Table 1. Treatment Types and Removal Efficiencies for Selected EDCs*

Compound	Process Type	Removal Efficiency
PCB (polychlorinated biphenyls)	Biofiltration	90%
	Activated sludge	96%
	Biofiltration/activated sludge	99%
NP (nonylphenol)	High loading/non-nitrifying	37%
	Low loading/nitrifying	77%
NP_1EO**	High loading/non-nitrifying	-3% produced as degradation product
	Low loading/nitrifying	31%
NP_2EO**	High loading/non-nitrifying	-5% produced as degradation product
	Low loading/nitrifying	91%
NP_6EO**	High loading/non-nitrifying	78%
	Low loading/nitrifying	98%
17β-estradiol/17α-ethinylestradiol	Filtration – Sand/microfiltration	70%
	Advanced treatment - Reverse osmosis	95%
Organotins	Primary effluent	73%
	Secondary effluent	90%
	Tertiary effluent	98%
Triazines	Conventional two-stage	<40%

*Taken from Birkett and Lester (2003).

**NP_nEO = Nonylphenol ethoxylate, where *n* = specific number of EO groups

Table 1 indicates that several compounds undergo significant degradation through biological treatment, particularly in nitrifying systems with longer SRTs. While sand filtration or microfiltration appear to remove 17β-estradiol and/or 17α-ethinylestradiol with decent efficiency, removal rates for other contaminants will be higher or lower depending on their association with colloidal or particulate matter. The more advanced membrane treatment option shown, reverse osmosis, provides a significantly higher removal rate, though it is important to realize with this technology that the contaminants removed from the main waste stream are concentrated in a smaller reject stream which may require further treatment and must be disposed of properly.

Depending on the type of contaminant involved, coagulant addition, as is practiced for various reasons at many WWTPs, might help to remove some EDCs and PPCPs, particularly those associated with colloidal or particulate matter. However, many of the EDCs and PPCPs of concern are relatively polar with log K_{ow} values of less than three, so a high degree of removal by partitioning onto particles is not expected. In general, research has not shown that coagulation and flocculation with alum and ferric is particularly effective for removal of PPCPs and pesticides (El-Dib and Aly, 1977; Adams et al., 2002; Yoon et al., 2002). It should also be noted that if a coagulant was used as an adsorbent for a particular EDC or PPCP, the resulting sludge could be hazardous and may require special handling.

Estrogenic Chemicals and Biological Treatment

Though there are many chemicals released into the water environment that are potential EDCs, most work reported to date has focused on xenobiotic estrogens of the alkylphenol group and steroid estrogens, since these two groups of chemicals have demonstrated estrogenic effects in fish. Thus, most of the information presented in this section will pertain to these particular groups of contaminants.

The parent compounds of these two groups, alkylphenol polyethoxylates (APEs) and estrogen conjugates, are not particularly estrogenic; the potentially hazardous estrogenic intermediates are formed because the parent compounds are only partially broken down through wastewater treatment. APEs are nonionic surfactants used in a variety of industrial and household applications, and breakdown into nonlyphenols, octylphenols, and a wide variety of other intermediates during wastewater treatment. Humans excrete natural and synthetic steroid estrogens in inactive forms, which are converted to active hormones, such as estrone (E1), estradiol (E2), ethinylestradiol (EE2), and estriol (E3), in the sewer and through treatment (Johnson and Sumpter, 2001). (EE2 is excreted only when birth control pills are used.)

Many different researchers have reported on the presence of EDCs and/or PPCPs in wastewater and their fate through the biological wastewater treatment process. Studies from research efforts around the world include work by Belfroid et al., 1999; Ternes et al., 1999; Baronti et al. 2000; Korner et al., 2001; Svenson et al., 2002; D'Ascenzo et al., 2002; Lee and Peart, 2002; Andersen et al., 2003; Giger et al., 2003; and Huang, Y., 2003. These authors report a range of removal results for a variety of chemicals, though effluent concentrations of the estrogenic compounds were often found to be in the lower ng/L range, and below detection limits in some cases. In comparing between different studies on the fate of various chemicals through wastewater treatment, it is important to keep several important facts in mind. First, treatment conditions and objectives, such as HRT, SRT, temperature, pH, nitrification, denitrification, and bio-P, are often not sufficiently described by researchers. These factors can have a significant impact on EDC removal rate at any given plant. Second, sampling strategy and analysis can dramatically affect results. Third, spiking the influent to a biological process with high concentrations of contaminant may select for an adapted population of microorganisms that would not normally develop (Johnson and Sumpter, 2001).

This section focuses on the impact of biological treatment design on EDC removal, since that is the key component of a conventional WWTP for EDC/PPCP removal. A recent study in England showed particularly dramatic benefits of adding a biological step. Simply adding a short secondary treatment stage of fine bubble aeration to a domestic WWTP that previously had only primary settlement produced a sudden and sustained reversal in feminization trends in downstream fish (McCann, 2004).

Not all types of biological treatment provide the same degree of benefit. For example, Ternes et al. (1999) and Korner et al. (2001) both observed that trickling filters (TF) were less efficient at reducing the estrogenic content of influent wastewater than activated sludge. More recently, two WWTP in the southwestern U.S. were observed. Both plants have primary clarification and effluent filtration, but the biological process of one plant is a Bardenpho BNR activated sludge system with a solids retention time (SRT) of 10-13 days, and the other is a TF system. Both plants receive primarily domestic influent and operate at an average temperature of about 20 degrees C. A comparison of the effluent concentrations of several potential EDCs and PPCPs, a few of which are the known estrogenic compounds, are shown in Figures 2 and 3.

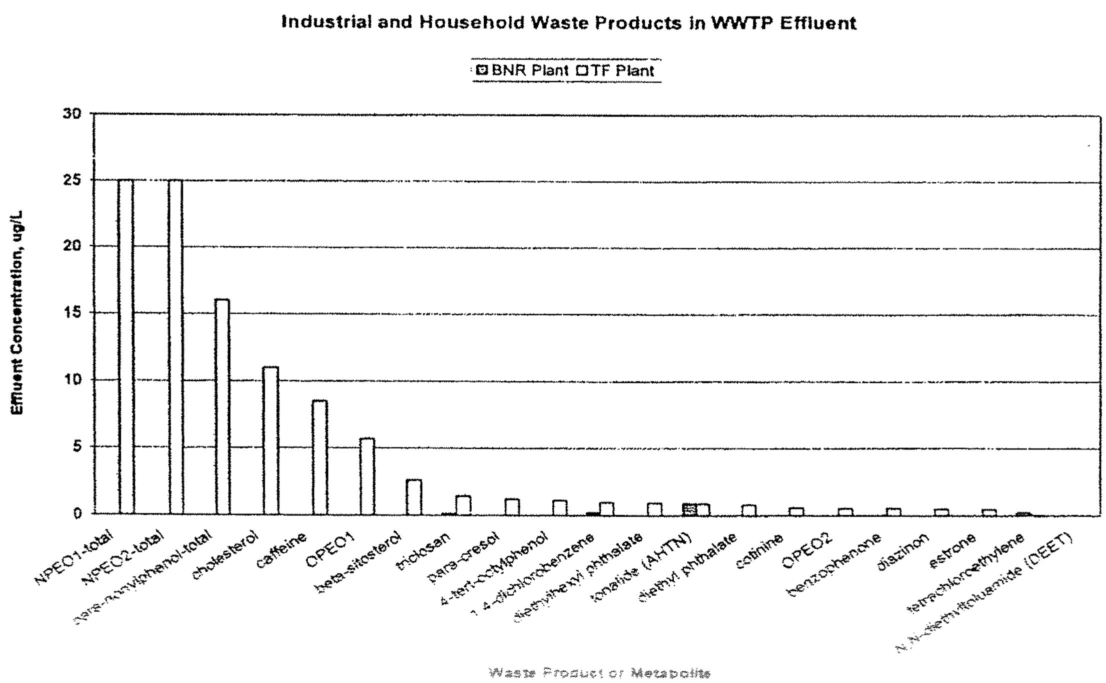

Figure 2. Comparison of Waste Products in BNR and TF WWTP Effluent

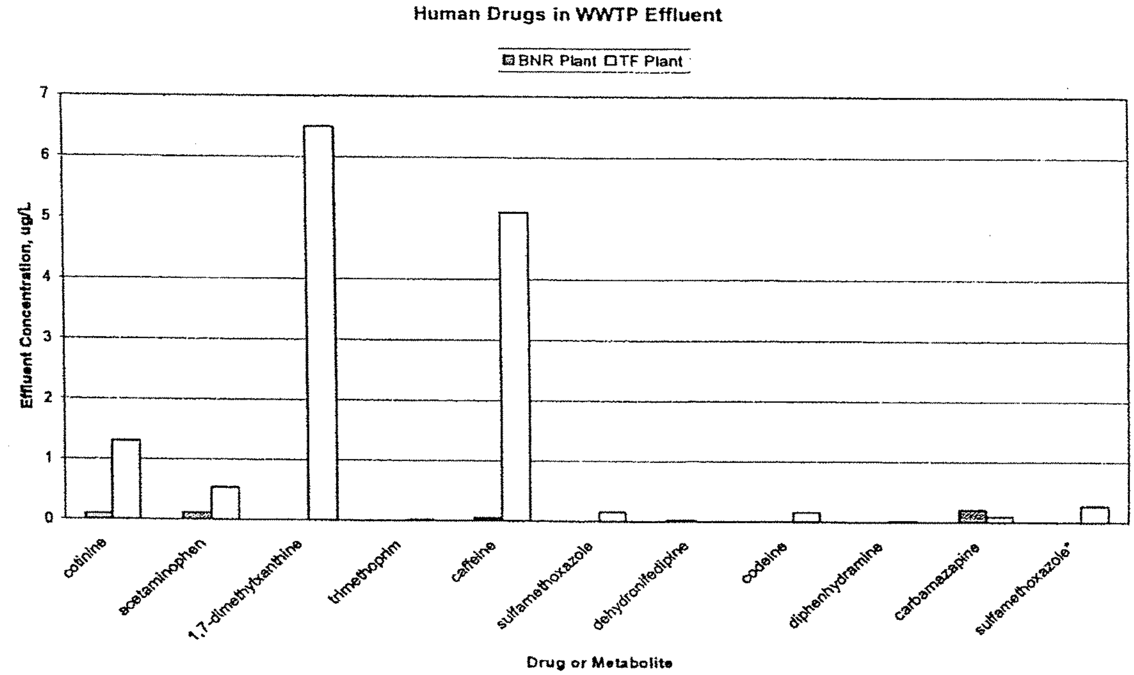

Figure 3. Comparison of Human Drug Concentrations in BNR and TF WWTP Effluent.

From Figures 2 and 3, it can be seen that the activated sludge system does a generally superior job of micropollutant removal as compared to the TF system. Though the more recent studies demonstrate analytical capabilities for measuring EDCs and PPCPs down to the nanogram per liter level, the concentrations shown here in micrograms per liter still provide an excellent comparison of process capability.

In activated sludge systems, hydraulic residence time (HRT) and/or SRT seem to be especially important factors in EDC removal. The longer the HRT, the longer the time available for biodegradation. The HRT of most European activated sludge systems is between 4 and 14 hours (Johnson and Sumpter, 2001), which would explain why this type of treatment would provide better performance than a TF, which might have an HRT of less than one hour. An increase in SRT may enhance the biodegradative and sorptive capacity of the activated sludge. The longer SRT could lead to a more specialized microbial population that can adapt to removal of EDCs and PPCPs. SRT also influences the hydrophobic or hydrophilic properties of the flocs and their ability to act as sorbents.

Several researchers have noted improved EDC removal with increased SRT (Ternes et al., 1999; Holbrook et al., 2002; Andersen et al., 2003). Saino et al. (2004) even specify that SRTs of at least 10 to 12.5 days are required for the organisms that decompose E2 and E1 to grow. In existing WWTP where it may not be possible to adequately increase the SRT because of expense or site constraints, MBR could offer advantages of more flexibility to operate at higher SRTs in a smaller footprint. While microfiltration membranes themselves will not provide an enhanced degree of EDC removal, it has been suggested that EDC adsorption to particulate matter that is retained by the membrane would reduce EDC concentration in the effluent. Ivashechkin et al. (2004) operated conventional activated sludge and MBR pilot units in parallel, operating both for denitrification at two different SRTs (12 and 25 days), and applying the same influent wastewater and sludge loading rate to each system. They did not find an appreciable difference in removal of nonlyphenol (NP), bisphenol A (BPA), and 17α-ethinylestradiol (EE2) between the two systems. The authors determined that EDC removal was due primarily to biodegradation; removed EDCs were not simply sorbed onto sludge particles, nor were they retained in the membrane material or the membrane biofilm. Other researchers, however, have found that microfiltration membranes are able to display some retention of smaller particles or colloidal material onto which EDCs may adsorb (Holbrook et al., 2003; Wintgens et al., 2004). Since pore sizing of membrane material is not uniform between manufacturers, it is possible that a difference in membrane material may explain some of the discrepancies in colloid retention. Differences in limits of detection also likely play a role.

Influent and effluent EDC and PPCP data was also collected from a BNR WWTP in the western U.S. that operates at an average SRT of six days and a temperature of 25 degrees C (Snyder et al., 2003). A pilot MBR was also run in parallel at a much higher SRT. The differences in removal rates for some chemicals are shown in Figure 4. Hormones E1, E2, EE2, E3, progesterone, testosterone, and androstenedione were removed to below detection limits (10-25 ng/L) in both systems. It is likely that the increased removal efficiency of the MBR for some compounds was due to the higher SRT, though it is possible that the filtering action of the membrane contributed.

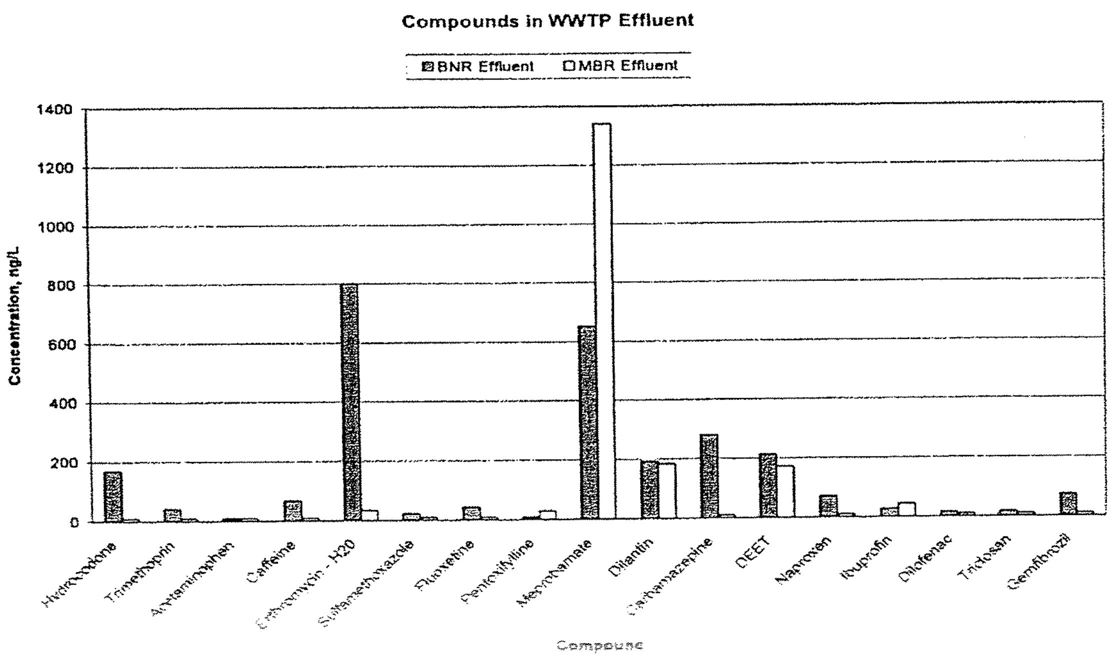

Figure 4. Comparison of Removal Rates Between High SRT MBR System and BNR System

Johnson and Darton (2003) state that E1, E2, EE2, and NP are all "inherently biodegradable and so in theory should not present an intractable problem." A drastic increase in the SRT or HRT of existing WWTPs to allow more complete biodegradation would be both cost and space prohibitive, but application of advanced tertiary treatment technologies for many communities would be far too costly. The alternative approach that they propose is to locally increase the amount of biomass sorbent by providing a carrier material within the activated sludge basin onto which a biofilm can develop. A wide range of mild to strongly hydrophobic organic contaminants would be intercepted by the bacterial surfaces and biodegraded. They propose a fixed surface rather than mobile carrier particles to ensure contact of influent wastewater with the biofilms. The fixed matrices would be located toward the front end of an aeration tank (some degree of plug flow is desired) and would be laid out in several packed zones. Laboratory scale tests have shown that almost all steroid estrogens can be removed by this process at a modest extra cost to existing facilities.

With reference to pollutant adsorption onto activated sludge, many EDCs or PPCPs of concern tend to be hydrophilic, though a few of the estrogenic compounds discussed in this section, like octylphenol and EE2 to some extent, are more hydrophobic (Yoon et al., 2003). Such chemicals can adsorb to and concentrate in activated sludge, and may survive anaerobic digestion. Thus, land application of biosolids is another route of exposure for some EDCs to enter the environment, though the ecotoxicological significance of this is presently unknown (Johnson and Darton, 2003).

In summary, it has been shown that some WWTPs are capable of removing most if not all estrogenic activity, with secondary biological treatment being the key process (Pickering and Sumpter, 2003). These facilities should be studied to determine the reasons behind their success. Where it is not possible to increase SRT and/or HRT at an existing WWTP exhibiting less than optimal performance, addition of advanced tertiary treatment may be the only option if ultra low concentrations of EDCs are eventually required. However, it makes sense that we should first thoroughly research optimization of the activated sludge process as a cost effective treatment process that does not generate additional side streams requiring further treatment and disposal.

Formation of Disinfection By-Products in Wastewater Treatment

All forms of typical wastewater disinfection practiced today will generate disinfection by-products (DBPs) to some degree (White, 1999). The EDSTAC has recommended that DBPs be evaluated for potential endocrine disruptive effects, as it has been suggested that DBPs formed though wastewater disinfection can act as EDCs. The latest research from Japan (Itoh et al, 2004) indicates that chlorination as performed at many WWTPs increases the estrogenic effect of waters containing natural organic matter (NOM). Though chlorination increases the estrogenic effect of NOM and a few other substances, many individual compounds are decomposed by chlorine, drastically decreasing the overall estrogenic effect. For this reason, the authors stress that the *overall* estrogenic effect be evaluated as the sum of increased and decreased activity by chlorination. Because DBPs are suspected to have toxic properties and are generally present in much higher concentrations in WWTP effluent than EDCs or PPCPs, efforts to control EDCs or PPCPs by oxidation may be counterproductive since additional DBPs may be produced (Snyder et al., 2005b). The two main ways that DBP production can be controlled are to 1) control the precursors that react with the disinfectant/oxidant or 2) allow the DBPs to form and then use a separate process to remove them (Marhaba, 2000). Various strategies are being evaluated to determine the best approach.

RESEARCH INTO ADVANCED TECHNOLOGIES FOR EDC REMOVAL

Biological processes are usually the most cost effective means of removing organics from wastewater, but when these organics are toxic or non-biodegradable, physical and/or chemical methods must be used. These methods include adsorption, chemical oxidation, and membrane processes that have more typically been used for water treatment. Research into advanced EDC/PPCP removal strategies is being conducted worldwide. The following is a sampling of new and traditional technologies that appear to have good potential for full-scale application if ultra low EDC/PPCP concentration limits are imposed. It is not suggested that any of these technologies be incorporated into current upgrade/expansion designs at WWTPs, but rather that the potential for EDC/PPCP regulation be recognized by designing flexibility into any long-range upgrade/ expansion plans.

Activated Carbon Adsorption

Activated carbon has been shown to remove many different types of EDCs and PPCPs to varying degrees. Adsorption will depend on the properties of both the sorbent and the contaminant. Activated carbon efficiently removes hydrophobic organic compounds, but can remove some polar ones as well depending on the strength of polar interactions (Snyder et al., 2003b). NOM also competes for adsorption, so lower NOM content in the water will lead to more efficient use of carbon.

Activated carbon is generally applied in one of two forms: 1) powdered activated carbon (PAC) is added to a sedimentation or contact basin, contacted with water for a few hours, and removed through settling and/or filtration, and 2) granular activated carbon (GAC) is in the form of adsorptive packed beds or filters with continuous flow and short (< 30 minutes) contact times, and can stay in operation for months or years (Snyder et al., 2003b). Adsorbents are very effective for achieving a high degree of removal and low effluent concentrations of contaminant by removing the contaminant from the liquid phase onto the activated carbon. Once exhausted, the adsorbent must be either disposed of or regenerated. The former option merely transfers the pollutant from liquid to solid phase, and the contaminant-rich activated carbon may require further treatment prior to disposal. The latter option can be very costly. Brown et al. (2004) are conducting studies to develop a non-porous adsorbent that can be regenerated in a quick and cost effective manner.

PAC has been shown to achieve over 90 percent removal of E2, EE2, and other potential EDCs from distilled water (Yoon et al, 2002). Wintgens et al. (2004), however, examined use of GAC following MBR treatment of landfill leachate and found that performance was relatively poor for removal of BPA with only 1.3 g/d of an influent 3.4 g/d being adsorbed. Adams et al. (2002) studied the removal of seven antibiotics from both distilled water and river water using common PAC dosages. They found no statistical difference between the removal results from the two different waters, and concluded that PAC was a viable means of providing treatment for the pharmaceuticals studied. Miltner et al. (1989) also showed that GAC represented a cost effective means of controlling several pesticides. Full-scale information on use of activated carbon for EDC/PPCP removal is not available at this time.

Ozonation

Ozone is a powerful, but selective oxidant. During ozonation, molecular ozone and hydroxyl radicals, to some extent, may transform EDCs and PPCPs (Yoon et al., 2002). While ozone has been commonly used in water treatment, its application for EDC/PPCP removal at WWTP is only now being studied. Wintgens et al. (2004) performed ozonation on a BNR effluent to determine whether trace levels of NP and BPA could be removed. Very low effluent pollutant concentrations were measured for ozone doses of 8, 10, and 15 g O_3/m^3, with no appreciable increase in removal rate with dose. In a German pilot unit, application of ozone to BNR effluent resulted in some removal of over 50 trace organic pollutants that are typically found in wastewater effluent, with removal efficiencies frequently higher than 90% (Ried et al., 2004). Three important EDCs – E1, E2, and EE2 – were effectively oxidized or degraded by ozone, and the authors suggest that they lose most of their estrogenic potency in the process. In addition, antibiotics were no longer detected in the effluent. Ozone was not particularly effective in oxidizing iodinated contrast media compounds, and AOP combinations with ozone did not significantly enhance removal rates.

The nature or concentration of ozonation by-products were not discussed in either study. Formation of DBPs with ozone is an important consideration since some amount of NOM will be present in wastewater effluent. Bromate and brominated organic compounds are of particular concern when waters being treated contain bromide.

Advanced Oxidation Processes (AOPs)

Combinations such as UV plus hydrogen peroxide, ozone plus hydrogen peroxide, and UV plus ozone are powerful oxidation processes that effectively oxidize contaminants. These combinations are designed specifically to increase the concentration of hydroxyl radicals formed, since hydroxyl radicals have less selectivity as oxidants. Substances that are difficult to biodegrade and not removed are oxidized, and the oxidized byproducts may be more amenable to biodegradation. AOPs can be followed by a biological process to further degrade the byproducts, or natural purification processes may be relied upon for treatment, depending on the situation (Ried and Mielcke, 2003). As with ozonation, the hazard potential of the byproducts formed through treatment is also a topic of investigation.

Ried et al. (2004) estimated costs of low pressure UV, ozone, and three AOPs. This information was converted into U.S. units and is presented in Figure 5. As another point of comparison, Ried et al. (2004) reference the total cost for a membrane step at an equivalent of $1.8 - $2.2 per thousand gallons.

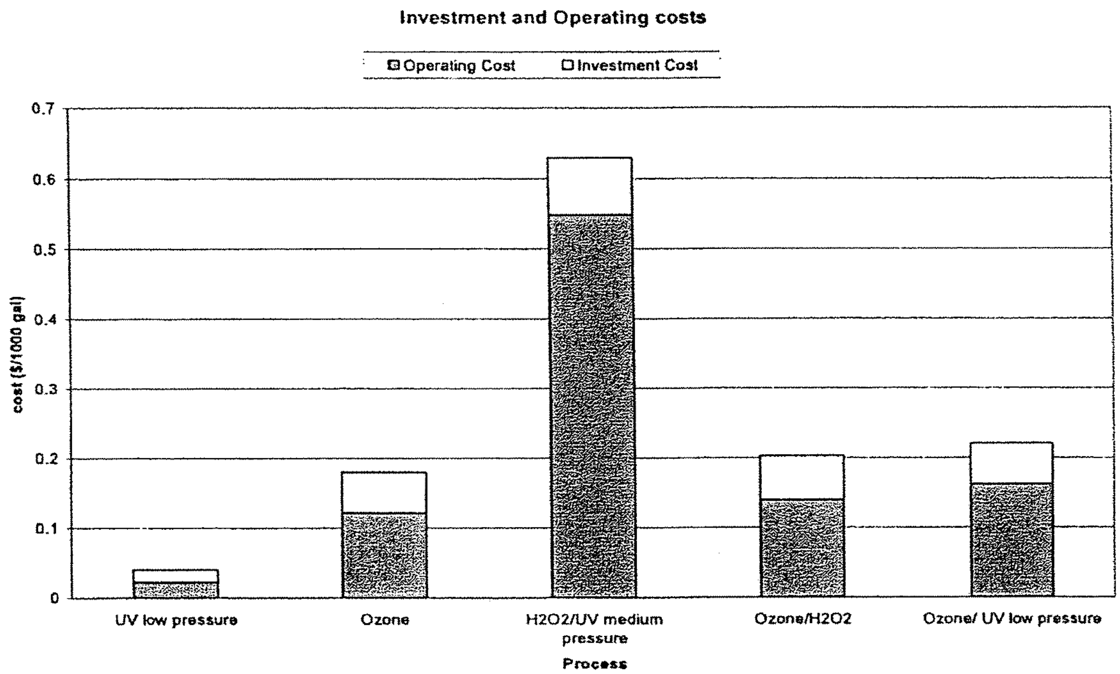

Figure 5. Comparison between UV, Ozone, and AOP Capital and Operating Costs (adapted from Ried et al., 2004).

Reverse Osmosis (RO) and Tight Nanofiltration (NF) Systems

These types of membranes can reliably remove most EDCs and PPCPs, depending on compound size and membrane properties. Microfiltration is required as a primer step. Besides the advantage of effective removal of micropollutants, DBPs are not created in the treatment process. However, RO and NF systems are very expensive and produce a concentrated reject stream that requires further treatment.

Adams et al. (2002) used a low-pressure RO system to remove antibiotics from distilled and river water. Removal rates in both cases were about 90%. With two and three RO units in series, removal rates increased to 99 and 99.9 percent, respectively.

Wintgens et al. (2004) showed that concentrations of E1, E2, and EE2 in MBR effluent could be reduced to very low levels using NF and RO. The effluent hormone concentrations from RO were extremely low, but not zero, and effluent concentrations from NF were slightly higher. Consequently, the hormone concentrations in the reject stream from the membrane processes were extremely high. Depending on the level of hormone concentrations ultimately deemed "insignificant" in the water environment, either NF or RO could be useful as a polishing step, but the concentrated reject stream will pose a new treatment/disposal challenge. RO and NF systems are usually not an economical option at WTPs (Adams et al., 2002) and are therefore not expected to be economical at WWTPs either.

DESIGNING FOR FLEXIBILITY

Future regulatory requirements are unknown at this time, though it is possible that limits on some EDCs may be included in wastewater effluent discharge permits in the future. Several advanced technologies, such as AOPs and RO, have been shown to successfully remove potential EDCs and PPCPs from water. Most of these options, however, involve significant capital and operating expenses that may not be justifiable at this time, since clear regulatory guidance is not available.

In long-range design plans, flexibility should be included to accommodate possible EDC regulations. Potential treatment strategies could be incorporated into existing layouts, and it is important to leave room, both on the site and within the hydraulic profile, for new equipment. The conditions and waste characteristics at every WWTP are unique, so design of the most feasible or cost-effective EDC control strategy will be case-specific. Process selection criteria such as space requirements, byproduct issues, and compatibility with existing facilities must be discussed. Pilot trials will be essential for an optimized design and confirmation that treatment goals can be met. Planning should favor processes and management strategies that will address not only the concern for EDCs, but other water quality goals as well. In this way, capital expenditure will have a broader basis than resolving this one issue that has an unclear outcome.

One option for consideration is the multiple-barrier approach for the protection of public health. This approach includes additional equipment for multiple modes of defense against contaminants (i.e., biological oxidation, physical separation, and chemical oxidation). This could mean the use of activated sludge, filtration, and AOP, or MBR followed by RO and disinfection/oxidation. Incorporation of MBR or integrated fixed film activated sludge into existing biological treatment systems should be considered for enhanced EDC removal where site constraints exist. The higher-level technologies could be added as necessary to meet future treatment requirements. The formation of DBPs can be minimized by strategic positioning of any advanced technologies in the treatment train (e.g., oxidation following filtration).

Though there are several utilities, particularly in the western U.S., that are already considering use of higher-level technologies for EDC or DBP control, it is important to remember that regulations for EDCs and PPCPs are not yet in place. Some utilities are trying to stay ahead of the curve by considering treatment options based on where they think federal or state regulations are headed. In other cases, they may be responding to local demand brought about by public perception of water contamination.

Example and Cost Estimate

The following example describes options that could be considered at a WWTP for enhanced reduction of potential EDCs. The first two options would involve upgrading the existing activated sludge basins to gain a significant amount of SRT; as mentioned previously, many chemicals of concern may be removed by providing adequate SRT. This amount of treatment might be sufficient to meet any new permit requirements. If a higher degree of treatment is required, however, one of several advanced treatment options may be added to suit the situation. Such higher-level tertiary treatment technologies use a powerful oxidation or straining step, and the associated expense is far greater. Table 2 shows a range of the equipment costs and operation and maintenance costs for each of the options, based on Black & Veatch design experience. The costs given for the AOPs do not match those shown on Figure 5, probably because of the differences in chemical and/or energy use and the equipment included. Additional considerations for each option follow Table 2.

Table 2. Equipment and O&M Costs for EDC Removal Options.

Process/Technology	Estimated Equipment Cost[1] ($/gal)	Estimated O&M Cost ($/1000 gal)
MBR	1.00 – 2.50	[2]
IFAS	0.20 – 0.30	[2]
Peroxone	0.40 – 0.80	0.40 -0.80
UV/Peroxide	0.40 -0 .60	0.30 – 0.50
MF/RO	1.65 - 3.74	0.60 - 1.00
MF/RO followed by UV/Peroxide	2.05– 4.34	0.90 – 1.50

(1) Does not include cost of construction.
(2) Separate costs not determined.

MBR and IFAS: These options maximize use of the existing facilities. Both have small footprints and can achieve high SRTs in small tank volumes. The consideration and use of MBR technology around the world is advancing rapidly, driven by the increasing need for high levels of treatment and/or small footprint technologies for both municipalities and industries. Most MBR installations are less than 10 years old; therefore, the design criteria for removing micropollutants using this technology are still evolving. Until recently, only a limited number of manufacturers have been offering this technology. Now, numerous MBR vendors offer systems with significantly different configurations, design approaches, and micropollutant removal efficiencies. In the event that a higher degree of treatment is needed in the future, MBR can also serve as the primer step for RO.

The IFAS process combines fixed-film and suspended activated sludge processes. Fixed film media is available from many manufacturers in the form of plastic elements, string systems, plastic webs, and sponges. Adding this media to existing aeration basins makes it possible to achieve nitrification and removal of micropollutants with less basin volume than would be required for a comparable single-stage activated sludge nitrification process. Further, the added media provides surface area for the growth of nitrifying bacteria without imposing excessive solids loadings on the final clarifiers, because the beneficial microbes remain attached to the media in the aeration basin.

Peroxone: Peroxone, or ozone/peroxide, has been used for a number of years to remove trace pollutants from groundwater. It has also been installed as part of a multiple-barrier approach at numerous potable water treatment facilities. Because of the hydroxyl radicals formed, peroxone has been found to be very effective for removal of DBPs. Costs are site-specific, depending on the flow rate and type of pollutant being removed.

UV/Peroxide: UV/peroxide has been shown to remove trace pollutants such as DBPs, toxic organics, NDMA, EDCs, and 1,4-dioxane. It forms hydroxyl radicals to oxidize the various pollutants. Carbon dioxide and water are the products of complete oxidation of the various pollutants. For some specific trace pollutants, only UV may be needed, though the UV doses would have to be unreasonably high to obtain appreciable removal of most EDCs or PPCPs. Of the AOP options, UV/peroxide may result in the lowest DBP formation. Pilot testing should be conducted to confirm costs Equipment costs for this option are the lowest of the advanced technologies, shown at about $0.50 per gallon, but to put this in perspective, this means that the equipment cost for a 20 mgd facility may be as high as $10 million, which does not even include the cost of the building.

MF/RO: Microfiltration followed by reverse osmosis has been used to remove trace pollutants from potable water. Additional research is being conducted to increase the throughput capacity of membrane systems. These types of systems will generally remove DBPs, EDCs, and PPCPs that have a molecular size larger than the molecular cutoff of the membrane system.

MF/RO plus UV/Peroxide: MF/RO followed by UV/peroxide is an example of a multi-barrier approach. Both processes can independently remove a variety of DBPs, EDCs, and PPCPs. Any trace amount that may pass through the membrane process is oxidized by UV/peroxide. As shown in Table 2, UV/peroxide is the most expensive option; however, it is also the most complete barrier for removing pollutants.

Figure 6 provides an example of how these and other options might be designed into an existing wastewater treatment system.

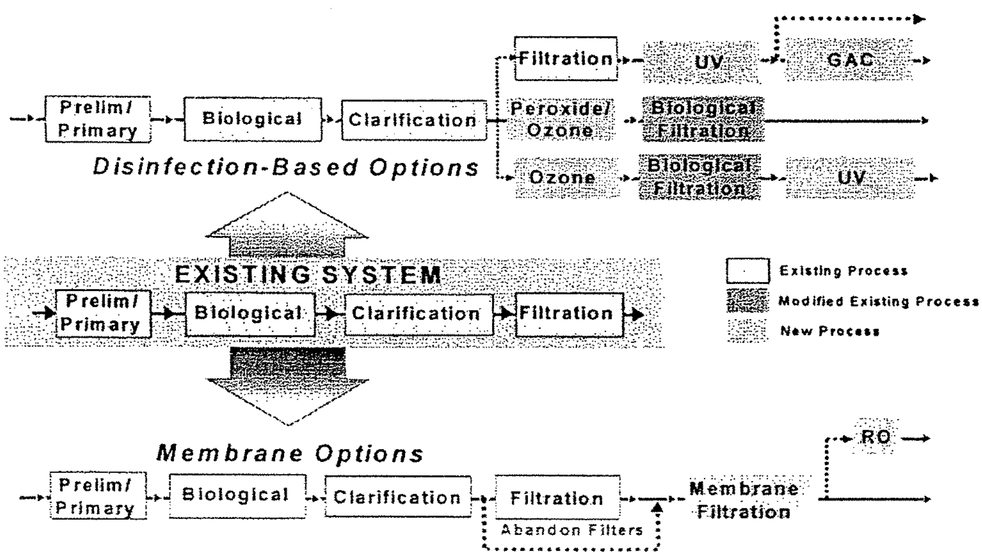

Figure 6. Designing for Flexibility at an Existing WWTP

WHERE SHOULD TREATMENT EFFORT BE FOCUSED?

Effects of endocrine disruption on wildlife exposed to estrogenic and other chemicals in the water environment have been demonstrated over the past several years. The public has expressed concern about its safety, because the public drinking water sources may contain trace amounts of chemicals that have been shown to cause adverse health effects in fish and other aquatic organisms. Effects on human health cannot be easily extrapolated from effects on aquatic organisms, however, because aquatic organisms are subjected to continuous exposure to these chemicals, whereas human exposure is generally limited to the amount of water consumed. Further, aside from DBP concerns resulting from disinfection, public drinking water supplies have yet to be proven to be causing adverse effects to human health. While it has been shown that high-tech methods such as reverse osmosis and various advanced oxidation processes can remove many suspected EDCs with impressive efficiency, these methods are generally costly and do not solve the problem of environmental pollution if they are installed at the water treatment plant.

It has been demonstrated through many studies, Johnson et al. (2000), Ternes et al. (1999), and Baronti et al. (2000), to name a few, that activated sludge systems have the potential to remove many suspected EDCs to a fairly high degree. The biological process can likely be optimized to achieve an even higher degree of treatment as researchers further study the effects of SRT, HRT, and other parameters. Attempts to achieve a higher level of treatment with activated sludge should be made before resorting to advanced technologies for EDC removal at WWTPs that may be cost-prohibitive for many communities.

This is not to suggest that the current efficiencies of our WTPs be relaxed; the importance of minimizing DBPs and the contaminants that make their way into water sources through runoff, leaching, and other means is recognized. But based on our current knowledge, it seems logical that a major focus of EDC and PPCP removal should be at the WWTP. Removal of these pollutants from WWTP effluent may solve much of the apparent endocrine disruption problem in the water environment, in addition to providing a cleaner source for drinking water. New data may indicate that tighter controls on industry and agriculture/livestock operations should be required as well to make a more significant difference. Once the scientific community has identified "safe" levels of exposure for the affected organisms, any WWTP effluent limits on contaminants of concern can be targeted to support the health of the water environment.

CONCLUSIONS AND RECOMMENDATIONS

Though EDCs are currently not regulated in the U.S., the possibility exists that future regulations will be established for some EDCs in WWTP effluent. Processes are available to remove many, if not all, EDCs and PPCPs from wastewater. Since with adequate retention time, a biological treatment system may achieve complete biodegradation of many chemicals of concern, cost effective options for optimization of the activated sludge process should be explored before investing in advanced treatment technologies with high capital and O&M costs. The issue of by-product formation must be researched further, since chemical or biological oxidation can successfully eliminate a parent compound, only to produce potentially more hazardous breakdown products. The potential additive effects of some EDCs must also be considered in the design of any treatment system.

It is recommended that some degree of flexibility be included in long-term WWTP design to take into account the potential for new regulations on EDCs. Before specific process components can be recommended for treatment of emerging contaminants, however, the scientific community must identify the hazardous contaminants, determine their acceptable concentrations (singly and in combination), and establish standardized analytical methods for their detection. Various conventional and advanced technologies can be assessed for their removal capabilities, and it can be determined whether any additional processes are required at WWTPs to achieve necessary removals.

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Policy

Policies

Effluent Reuse

Definition

There is no one universal definition as to what effluent reuse comprises but in general it is considered to cover the reuse of wastewater for what ever purpose which may or may not involve treatment.

Wastewater can comprise:

- effluent from municipal sewage works
- waste water from industrial processes
- wastewater from household properties

Reuse should comprise:

- potable water supply
- non potable water supply
- industrial process water
- replenishment of water resources
- irrigation water

Existing Arrangements (UK)

The reuse of effluent to replenish rivers has occurred ever since the introduction of municipal wastewater treatment works. As an indirect consequence of this many lowland storage reservoirs, which rely on abstraction from rivers, will comprise a proportion of effluent. This is often referred to as the indirect use of effluent.

More recently the direct reuse of effluent from industrial processing for further industrial use has been practised. In some circumstances effluent from municipal wastewater treatment works has been used.

There are now examples of wastewater from household use, such as sink and bathrooms (grey water), being re-used as cistern flush water. There has currently been only one example of effluent from all household use (black water) being used for cistern flushing.

Effluent is also used directly and indirectly for the irrigation of crops.

In some areas treated effluent from sewage works is used to replenish groundwaters.

There are cases where wastewater from a municipal sewage works is diverted specifically to replenish flows in watercourses.

In one case this has allowed additional abstractions to help refill a reservoir which is used for public water supply. Although specifically engineered for the purpose in practice it is no different to historical arrangements referred to at the beginning of this section.

Possible Future Arrangements

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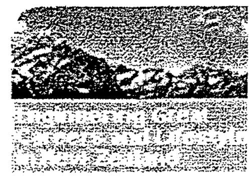
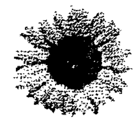
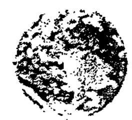




CIWEM's education & training initiatives

CIWEM Rivers and Coastal Group



CIWEM Factsheets

Sustainable development principles are firmly on the political agenda. This includes the need to minimise the consumptive use of natural resources, such as water, but bearing in mind social, economic and environmental factors.

The EA reference in their regional and national strategies that effluent reuse schemes specifically engineered to enhance water resources could help bridge the gap between supply and demand, especially in the growth regions of the SE of England.

The greatest potential for reuse may be in areas where effluents are discharged to the sea at present, as they could be diverted inland to support river flow and increased abstraction.

Industry is keen to reduce their environmental impact and to reduce costs associated with water supply and effluent discharge. There are many cases, often promoted and reported by Envirowise (DTI/DEFRA), where recycling opportunities have delivered significant savings.

The market for household effluent reuse is growing slowly but green field and new build are ripe for purpose built effluent reuse facilities. Installation of greywater systems on existing individual properties has a long payback period and is not attractive using current technology, particularly for retrofitting existing houses.

Recycling technology is developing and, with membrane technology now well developed, water can be treated for specific reuse purposes.

Issues for Discussion

(a) Although effluent reuse has been practised indirectly for decades through the existing water cycle of abstractions and effluent returns to rivers, there is an underlying concern over schemes directly engineered for that purpose.

(b) The water industry contends that existing standards of effluent consenting (to meet environmental quality standards and Directives) and conventional drinking water treatment is sufficient to protect public health. However there are others who are concerned about the build up of toxins and other "exotics" such as endocrine disrupters through wastewater recycling.

(c) There are also perception issues. Recent anthropological studies have revealed that the general public do not like experiencing other peoples waste and would possibly be concerned if they were aware of even current practices of indirect recycling. As the process of consultation is now widely practised, and will be reinforced through the Water Framework Directive, then not only will new schemes be exposed but concerns may be raised over existing arrangements.

(d) From these concerns the issue of whether or not additional standards for effluent quality that is to be reused for potable water, may need to be considered. There may also be a need for additional treatment reliability to reduce the risk of failure and breakthrough of contaminants.

(e) Changes in the volumes of effluent discharged to rivers could change an environment which has been accustomed to the discharges. There could therefore be an environmental change.

(f) The desire to promote water recycling should be considered in a holistic sustainable way. It is recognised that treatment processes are energy intensive and hence their environmental footprint needs to be considered and compared with more traditional methods of matching demand and supply.

(g) A coherent policy for effluent reuse is needed. This should define the responsibilities of DEFRA, the Environment Agency, and the Water Industry, and establish consistency of view between them. Standards should be realistic and attainable at reasonable cost, while still protecting public health, and protecting against adverse environmental impacts. Good science is needed to see if these ideals can be achieved.

Ed Smith and Derek Giles

L.A. Times Article Reprint
Water Recycling

- "the practice is on the rise ..."
- "projects ... will soon boost usage another 20% ..."
- "independent sewer and water utilities are ... merging."
- "officials estimate that it will cost ..."
- "Outreach to community groups ..."
- "No health problems have been reported ..."
- "to help endangered species ..."
- "a futuristic urban environment ..."

Los Angeles Times
Sunday Final
SUNDAY, AUGUST 17, 1997

Reclaimed Waste Water May Ease State's Thirst

Recycling: Despite 'yuck' factor, the practice is on the rise. San Diego is at cutting edge of what backers see as wave of future: sending treated sewage back to the tap.

By JILL LEOVY
TIMES STAFF WRITER

In an effort to help quench California's unending thirst, officials are set to embark on unusual plans to turn treated sewage into drinking water.

San Diego is preparing to pipe water from the local sewage treatment plant directly into the city's second-largest drinking water reservoir.

Communities in the South Bay and Livermore, Calif., have recently joined the Orange County Water District in approving the injection of treated waste water into underground supplies used for tap water.

Water recovered from treated sewage has already become an integral part of the state's water supply. Despite high costs and worries over public squeamishness, the use of "recycled" water has increased about 30% in the last, year.

It is being used to make snow for ski areas, grow hay, make newsprint and concrete, dye carpets, hose down landfills and fill cooling towers in oil refineries.

Critics counter that the process is expensive and may make many public water-drinkers opt for the bottled variety or turn up their noses and say, "Yuck!"

But Paul Gagliardo of San Diego's Metropolitan Wastewater Department believes that his city is about to begin "pioneering a process ... to get people comfortable with the idea of drinking treated sewage."

California spews enough sewage into the ocean to meet a third to half of the state's urban water needs, Gagliardo said.

He is among a small group of zealots who dream of a future in which Californians drink sewage, processed to levels similar to bottled water.

Those views are shared by crusaders such as Santa Rosa organic farmer Lawrence Jaffe, who sells vegetables nourished with recycled water using the slogan "Close the loop," and Bahman Sheikh, a San Francisco consultant who likes to make the point by gulping down a long, cool glass of tertiary effluent.

There is no reason to flush toilets with pure water from Mono Basin," Sheikh said.

Vater reclamation in some form has been going on for a long time. Irvine is the granddaddy of reclamation in California, setting an is yet unrealized goal in the early 1960s of recycling all its sewage water for non-potable uses. The Irvine Ranch Water District is still a leader, recently introducing reclaimed water to office air-conditioning systems.

op

WATER: Recycling Seen as Drought-Proof Way to Meet Growing Needs

The surge in water recycling has been propelled by improvements in technology, regulatory changes and a new crop of government subsidies for reclamation systems.

Today, California uses more than 450,000 acre-feet of reclaimed water annually. That is equal to about one-and-a-half Castaic Lakes, or the water consumed by two-thirds of Los Angeles in a year.

Projects now under construction will soon boost usage another 20%, according to the California Water Resources Board.

For all that, reclaimed water is less than 2% of the water used by farms and cities in California.

But advocates predict that will change, and cite models such as Irvine Ranch, where nearly a quarter of the water comes from treated sewage.

"It's like throwing money away if you just let this water go," said Jaffe, who spent his law school student loan to start an organic farm in the shadow of San Jose's treatment plant, where he grows vegetables using local compost and reclaimed water.

People such as Jaffe are fond of pointing out that while the state's reliance on water from the Sierra Nevada and the Colorado River is coming under attack, recycled water is the one source in California that is growing.

It is also drought-proof.

And because reclaimed water is produced locally by cities, it is also largely politics-proof. "No one can take it away from us," said Earle Hartling, water reuse coordinator of the Sanitation Districts of Los Angeles.

As a result, the uses of reclaimed water have multiplied so quickly that health officials have been scrambling to keep up. New regulations should be completed this year, said David Spath, chief of the division of drinking water with the state Department of Health Services.

The rules are expected to soon eliminate one of the ironies of this emerging water supply: its classification as a hazardous waste.

Until then, plant workers must fill out lengthy reports when they spill reclaimed water, even if it is drinking water quality.

Despite the regulatory confusion, recycled water is being used in a number of ways

It has been proposed as a source of water to do laundry at San Quentin Prison. It is even being pumped under the sea floor off Long Beach to keep the harbor area from sinking due to oil extraction. The oil companies have used tap water for this purpose—enough to supply 20,000 people with water for a year—but are switching to reclaimed water

top

Throughout the state, independent sewer and water utilities are cooperating, and in the case of San Francisco, merging. Their engineers are taking on dual roles, and converting acre-feet—the conventional measure of sewage

In short, water agencies now see waste water as a resource and incorporate it into long-term supply plans

Once chiefly an issue of handling sewage, reclaimed water is "moving over to the other side of the ledger," said Lou Garcia, director of environmental services for San Jose, which plans to divert nearly 40% of its sewage stream to water supplies in coming years.

The West Basin Municipal Water District, which serves communities from West Hollywood to Palos Verdes Estates, has made water recycling the linchpin of its plan to cut dependence on imported water in half over the next 20 years, largely by converting the region's water-hungry oil refineries to recycled water.

The purest of West Basin's recycled water is being injected into the ground to protect drinking water supplies from seeping seawater. The plan will simultaneously cut sewage discharge into the bay 25%.

San Diego leads the state. Officials decided to covert waste into drinking water after court rulings forced the city to better treat its sewage to protect the ocean. The result is water similar to what most people would consider good for a swimming lake.

Rather than dump that water back into the ocean, San Diego has designed a $150-million system to add another level of treatment, bring the water up to the quality of extra-pure tap water, and pump it to the city's San Vicente drinking water reservoir.

The water will be mixed into imported water supplies, comprising up to 10% of the supply by 2001.

"It's a very significant step," said Ken Weinberg, water resources supervisor for the San Diego County Water Authority. "We are creating a new source of water."

WATER: Use of Treated Sewage on Rise in State

The technology for recycled water has developed to where San Diego's water will supposedly be 10 times purer than tap water, Gagliardo said.

State health officials have already approved San Diego's plan, developing a new set of guidelines for the purpose because none exist. The water will be fine to drink, they say. The only worry is breakdowns in the system, so duplicate safeguards have been built in, Spath said.

top

San Diego officials estimate that it will cost about $600 per acre-foot to produce drinking water from waste water, about 30% higher than the cost of purchasing water from the Metropolitan Water District. They acknowledge that figure is fuzzy, however, because it includes federal subsidies and is counted against current sewage treatment costs.

And some San Diegans contend that it would be better spent on developing other water sources: "If you are willing to spend that kind of money, you could flood the city of San Diego," said Elmer Keen, a retired geographer and critic of the project.

But supporters counter that the cost of recycled water, although expensive, is still far less than the cost of desalinating water or building dams. "It's competitive in my book when compared to other new sources," said Peter MacLaggan executive director of th Water Reuse Assn. of California.

San Diego officials are keenly aware of how easily public perception of the project could go awry. "This issue," said one advocate Dr. Rosemarie Marshall Johnson, "gets everybody in a very personal way."

The city conducted focus groups to test monikers for the water, and ultimately chose "repurified" over "recycled," which it seems left too much to the imagination.

top

Outreach to community groups came next, with officials gingerly pointing out that the city's existing water source, drawn from the Colorado River, contains sewage that has been treated and discharged by cities upriver, such as Las Vegas.

"There are some people who find this abhorrent," Gagliardo said. "But we are already drinking discharged waste water. This is just throwing a lot of technology at it and doing it faster."

Across the state, similar public relations efforts are underway, with water agencies gently seeking to tell the public that they are using a new source of water that's quite close to home.

"All water has gone through countless other organisms before it gets to us," said Hartling. "Dinosaurs, fish, humans–some a lot more recently than we would like to think."

"It's a delicate balance," said Steve Kasower, water recycling specialist with the state Water Resources Board. "It's important the public understands this and doesn't get upset by fear-mongers ... But, dirty or clean, water is just molecules of H2O with stuff floating between them.

Public acceptance for water recycling is not without precedent.

top

In Northern Virginia, a sewage utility has been treating waste water so that it meets drinking water standards for 20 years and releasing it into the Occoquan Reservoir in an unusual project similar to what San Diego Plans. No health problems have been reported.

At the most advanced sewage treatment facilities today, utilities employ reverse osmosis and microfilter, devices that involve pressing water through microscopic membranes, similar to what is used at bottled water companies such as Arrowhead Water.

Elsewhere in the state, environmental regulation has also spurred new efforts at reclamation.

San Jose is one example. The city is under pressure to reduce the sewage it dumps into South San Francisco Bay, not because the discharge is poisoning anything, but because it is so high quality that it is converting natural saltwater marshes into freshwater ones.

"In effect, the water is too clean," said Steven Ritchie of the San Francisco Public Utilities Commission.

top

With bullrushes springing up in the bay where pickleweed once grew, and pressure mounting to do something to help endangered saltwater species, it was only a matter of time before cities like San Jose came to view their sewage as an enticing supply of freshwater, Ritchie said.

San Jose now has a $140-million reclamation system under construction that will deliver reclaimed water to parks, farms and industries in Silicon Valley, said Garcia, the city's environmental services director.

Some areas are even using reclaimed sewage water to upgrade the purity of their conventional water supplies

Monterey Regional Water Pollution Control Agency will unveil a $75-million project next month that will free farmers from dependence on wells that have grown too salty.

More than 12,000 acres will be served, making the project an unprecedented experiment in large-scale use of reclaimed water for agriculture, said the agency's Keith Israel.

Since statewide more than three quarters of urban water is used for things other than drinking, the most optimistic activists predict that someday 20% or even 40% would come from treated waste.

top

Toilet to tap" is the phrase that they use to denote a futuristic urban environment in which treated waste water would be transferred directly to drinking water pipes.

Such a system would require new technology to instantaneously detect germs in treated water. But some reclamation enthusiasts still see it as inevitable.

The very thought seems to make Spath, of the state health department, uncomfortable. "The time for that is not now, I will tell you that," he said

Even the strongest advocates sense that the quick turnover of water from sewers to faucets may be a bit to dicey to win wide public acceptance.

"I forbid you to print this," said Orange County reclamation advocate and farmer Charles Peltzer, while expounding ideas for mixing reclaimed water into public drinking water. "The public isn't ready to hear it."

Already, one water recycling plan has run afoul of the public: Three years ago, the Upper San Gabriel Valley Municipal Water District was forced to scale back a plan to replenish ground water with recycled water because Miller Brewing Co. voiced fears that the project might taint its nearby wells.

Other attempts to gauge public reaction have shown conflicting results. A few years ago in Denver, water agency officials conducted focus groups to find out how the public might feel about reusing waste water for drinking. They found to their surprise that many people would rather not think too much about where their water comes from. "They wanted us to just get on with it," said Jane Earle, of Denver Water.

In San Diego, similar consumer studies found that one people were briefed on water supply issues and treatment methods, they usually accepted the idea of recycling readily.

"(But) and initial reaction we hear frequently, 'Yuck,'" said cc consultant Sara M. Katz, who performed the studies.

Still, Jaffe, the Santa Rosa farmer predicts that reclaimed water will follow the same path as compost in the 1980s.

"No one says 'yuck' about compost anymore. It's mainstream. They make jokes about it on sitcoms. That's how reclaimed water should be. Not be exceptional, exciting or controversial. It should be normal."

top

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WATER ENVIRONMENT LABORATORY

SOLUTIONS

COVERING ANALYTICAL METHODS AND PRACTICES

Emerging Environmental Contaminants

Drugs and other chemicals are a growing challenge to water quality

Mary E. Sadler and Jane P. Staveley

Environmental chemists are using increasingly sophisticated analytical techniques to investigate the presence of previously undetected contaminants in surface waters. These emerging environmental contaminants (EECs) include thousands of chemical substances that have heretofore been largely outside the scope of monitoring and regulation in ambient waters.

These chemicals are not found on the priority pollutant list. They are, however, constantly being discharged into the aquatic environment from point and nonpoint sources in amounts believed to rival those of fertilizers and agricultural chemicals. Recently, EECs have received significant coverage in scientific journals as well as the popular press, along with speculation about their possible effects on human health and ecological processes.

There is no accepted or defined list of EECs. However, broad subcategories (see Table 1, p. 3) include veterinary and human antibiotics, prescription drugs (codeine, antiasthmatics, and antacids), nonprescription drugs (acetaminophen, ibuprofen, and caffeine), steroids and hormones (cholesterol and synthetic and natural estrogenic compounds), and organic wastewater contaminants (plastics, pesticides, detergents, fragrances, antioxidants, and antimicrobial disinfectants). Some of these chemicals have been recognized as endocrine disruptors. Research suggests that the effects of certain EECs on the endocrine system are elicited at extremely low concentrations, hence the concern for endocrine-active substances in the environment.

The detection of an EEC is not inherently or necessarily equivalent to risk to human health or the natural environment. Both exposure and toxicity are necessary to constitute a risk. In addition, people and aquatic organisms are exposed to a variety of chemical, physical, and biological stressors, making it

continued on p. 2

Synthesize 'Ethics at the Bench'

Most people regard the results of chemical and biological tests as definitive, but environmental lab analysts know that, even with strictly regulated testing, shades of gray are more prevalent than black and white. Judgment calls are routine and necessary in a water and wastewater lab, but that does not make them simple.

To help analysts make appropriate decisions, several organizations offer codes of ethics. Some are simple lists of responsibilities, such as the *Code of Ethics for Water and Wastewater Operators and Laboratory Analysts* published by the Association of Boards of

continued on p. 6

IN THIS ISSUE

WATER ENVIRONMENT LABORATORY
SOLUTIONS
COVERING ANALYTICAL METHODS AND PRACTICES

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difficult to interpret subtle effects and attribute them to a particular chemical detected at parts-per-trillion (ng/L) to parts-per-billion (µg/L) concentrations.

EEC Occurrence

The occurrence of pharmaceutically active compounds in the aquatic environment has been investigated in several studies in Austria, Brazil, Canada, Croatia, England, Germany, Greece, Italy, Spain, Switzerland, the Netherlands, and the United States. A summary of this research concludes that more than 80 compounds from various classes have been detected at concentrations up to the microgram-per-liter level in surface water, groundwater, and wastewater treatment plant effluent. To date, however, only a few instances of trace levels of these compounds have been found in drinking water. Figure 1 (p. 5) illustrates possible sources and pathways of EECs into the environment.

In March 2002, one of the most significant research papers to date on EECs in U.S. waters was published by the U.S. Geological Survey in *Environmental Science and Technology*. The USGS study sampled 139 streams for more than 95 wastewater contaminants during 1999 and 2000. USGS discovered that one or more of the analytes was found in 80% of the 139 sampled streams, 82 of 95 contaminants were detected at least once during the study, and 75% of the streams sampled contained more than one contaminant. A total of 33 of the 95 contaminants are known or suspected to show weak hormonal activity with potential endocrine disrupting properties, and all 33 were detected in at least one stream sample during the study. Measured concentrations of the contaminants were low, with few compounds exceeding drinking water guidelines, health advisories, or aquatic-life criteria where these values existed.

Health and Environmental Effects

Potential exposure pathways to surface water contaminants include direct contact, ingestion of water, and ingestion of food organisms containing the contaminant. If exposure can occur, the question to address is whether the magnitude, frequency, and duration of exposure are sufficient to produce an effect. In other words, is the EEC concentration high enough to cause effects, and do EECs occur often enough over a long enough period of time to produce effects?

One of the concerns about EECs is their potential for continuous input into surface waters. For example, when the general population uses pharmaceuticals, these substances (or their metabolites, which can be more or less biologically active) are then excreted, passing through wastewater treatment and maintaining a constant low level in the receiving water. Similarly, for veterinary products, a compound or its metabolites are excreted, and the resulting manure or slurry is released directly to the environment or applied to land, where the chemicals are subject to runoff or leaching.

Safe Dose?

A low concentration (nanograms per liter to micrograms per liter) of a particular drug in surface water is unlikely to represent a significant risk to humans, as the concentration is many orders of magnitude below the therapeutic dose. For most drugs, the therapeutic dose is based on extensive testing and includes safety factors to protect sensitive subpopulations. Using conservative assumptions, it has been estimated that lifetime consumption of a drug at the low concentrations observed in studies to date, through ingestion of drinking water at 2 L/d (0.5 gal/d), would lead to an exposure equivalent of only one or two therapeutic daily doses.

However, intentional human exposure to pharmaceutical and personal care products is structured. When receiving prescription medication or buying over-the-counter drugs, patients can be informed of conditions that are

Table 1
Emerging environmental contaminant categories

CATEGORY	CHEMICAL EXAMPLES
Human and veterinary antibiotics	Tetracycline, ciprofloxacin
Prescription drugs	Codeine, antiasthmatics, antacids, antidepressants, blood lipid regulators, antiepileptics, diclofenac[1]
Nonprescription drugs	Ibuprofen, acetaminophen, caffeine, aspirin
Steroids and hormones	Estrogenic compounds (estradiol, mestranol, testosterone), cholesterol
Plastics	Bisphenol A[2]
Detergents	Nonylphenol and octylphenol[3]
Antimicrobial disinfectants	Triclosan
Other	Fragrances, antioxidants

[1] Analgesic and anti-inflammatory drug.
[2] Known endocrine disruptor.
[3] Suspected of being hormonally active.

clude the use of certain drugs or be advised of potential drug interactions. Conversely, in surface water EEC contamination, the public is exposed unintentionally to a mix of various unknown contaminants during a long period of time that may potentially include sensitive periods. In addition, sensitive subpopulations — such as people with compromised immune systems or allergies — may be exposed.

While human pharmaceuticals and personal care products tend to undergo centralized wastewater treatment, veterinary products are released into the environment with minimal or no treatment. Thus, although the EEC concentrations in surface water may be extremely low and the potential for risk to human health is probably minimal, additional investigation certainly is warranted.

Ecological Effects

Of more concern is the potential risk to ecological receptors. Much less is known about the effects of EECs on aquatic organisms, but existing data indicate that aquatic life can be quite sensitive to at least some contaminants. [illegible]

required to secure regulatory approval for a new drug is vast, most of this information focuses on effects (both intended and side effects) on the user. The requirements for data on potential ecological effects vary considerably, depending on the relevant regulatory program. This may range from no data at all, to a base set of acute toxicity data on three aquatic species, to more extensive testing. While acute toxicity tests are good screening tools, they are insufficient for identifying subtle effects (on reproduction, growth, development, or hormonal homeostasis) that ultimately and significantly influence the aquatic ecosystem.

For example, hormones affect numerous physiological processes in both vertebrates and invertebrates. Female rainbow trout produce high concentrations of a protein called vitellogenin, a precursor of egg yolk. The occurrence of vitellogenin in male fish is an indicator of exposure to estrogen, and this response has been observed in male rainbow trout exposed to the biodegradation products of alkylphenol polyethoxylates, a major group of nonionic surfactants. Also, antidepressants appear to cause reduced [illegible]

docrine disruption in fingernail clams that affects reproductive processes. Thus, evidence is accumulating that the basic ecotoxicology tests are not identifying sublethal effects that could occur in aquatic animals.

Even less is known about the effects of EEC combinations that are likely to occur in the environment. The first study to investigate mixtures of pharmaceuticals in aquatic ecosystems found that a mixture of the painkiller ibuprofen, the antidepressant fluoxetine, and the antibiotic ciprofloxacin had significant effects on experimental microcosms. The microcosms, containing bacteria, zooplankton, phytoplankton, plants, and fish, were dosed with low, medium, and high concentrations of the mixture and observed for 35 days. The medium- and high-dose microcosms showed an increased abundance of phytoplankton and zooplankton, but community diversity decreased, and toxicity was observed in duckweed and sunfish. Although the drug concentrations used in the study were orders of magnitude higher than those reported in the environment, the effects were significant.

Wastewater Treatment Effects

Most of the literature available on pharmaceuticals in the environment deals with detection in the aquatic environment and not the environmental fate subsequent to treatment and release. Research data on pharmaceuticals in drinking water, surface water, and wastewater treatment effluent are inconsistent with respect to the removal efficiencies of different contaminants under different treatment schemes. More than 80 pharmaceutical compounds and their metabolites have been detected at very low levels in municipal wastewater treatment effluents and surface waters in Europe. Pharmaceutical compounds also have been detected in groundwater, particularly in areas potentially contaminated by landfill leachate or manufacturing residues. Other research has suggested that ozonation and membrane filtration [illegible] will remove pharmaceuticals from drinking water, surface water, or wastewater effluent. Table 2 (below) lists several categories of pharmaceutical contaminants and treatments that have been studied extensively in Europe.

Minimal data exist on the removal of pharmaceuticals as a result of primary, secondary, or advanced wastewater treatment. A 1981 study on the ability of 14 wastewater treatment plants to remove endogenous and synthetic estrogens found that 5% to 25% of synthetic estrogens was removed by facilities using primary treatment and 20% to 40% of synthetic estrogen was removed by those using secondary treatment. Between 35% and 55% of natural hormones were removed by primary treatment, and 50% to 70% were removed by secondary treatment. Research at the University of California at Berkeley on estrogen removal found that the removal efficiencies of microfiltration and filtration were nearly the same. Reverse osmosis achieved the highest rate of estrogen removal; however, some estrogens persisted in the effluent. A paper published in 2003 by Snyder et al. (*Environmental Engineering Science*, Vol. 20, No. 5) provides an excellent review of treatment technologies and potential removal efficiencies.

Path to EEC Regulation

In the United States, there are two pri-

Table 2
Summary of European pharmaceutical research

CONTAMINANT	TREATMENT TECHNOLOGY	LOCATION	REMOVAL EFFICIENCY	PRINCIPAL INVESTIGATOR
Salicylic acid	Wastewater effluent	Activated sludge	88% removal	Heberer
Diclofenac (analgesic and anti-inflammatory drug)	Wastewater effluent	Activated sludge	17% removal	Heberer
	Wastewater effluent	Activated sludge	69% removal	Buser et al.
	Drinking water	Bank filtration	Trace amounts in effluent	Verstraeten
	Drinking water	Ozone		Zweiner & Frimmel
	Drinking water	Membrane filtration	Trace amounts in effluent	Heberer; Sedlak
	Wastewater effluent	Membrane filtration	Trace amounts in effluent	Heberer; Sedlak
Ibuprofen	Wastewater effluent	Activated sludge	Significant removal, except for one metabolite	Stumpf et al.
	Wastewater effluent	Activated sludge	Significant removal (96% to 99.9%), includes all metabolites	Buser et al.
Antibiotics	Drinking water	Bank filtration	Significant removal	Heberer et al.
	Surface water	Raw water	Trace amounts in effluent	
	Wastewater effluent	Activated sludge	Trace amounts in effluent	Hirsch et al.
Antiepileptic drugs	Wastewater effluent	Activated sludge	< 10%	
	Drinking water	Bank filtration	No removal	Kuehn & Mueller; Brauch et al.; Heberer et al.
Beta blockers	Wastewater effluent	Activated sludge	Trace amounts in effluent	Hirsch et al.
Blood lipid regulators	Drinking water	Bank filtration	No removal, but metabolites removed	Scheytt et al.
Chemotherapy drugs	Wastewater effluent	Activated sludge	No removal	Kummerere et al.
Contraceptives	Wastewater effluent		Trace amounts in effluent	Desbrow et al.; Belfroid et al.; Spendgler et al.; Ternes et al.; Alder et al
	Wastewater effluent	Activated sludge	85% removal of estradiol	Baronti et al.
	Wastewater effluent	Activated sludge	No removal of estradiol	Ternes et al.
	Groundwater		Positive detection	Adler et al.
	Drinking water		Positive detection	Adler et al.

[illegible]

mary avenues for the regulation of chemicals in the environment: premarket and postmarket. In premarket regulation, chemicals are evaluated for their potential risk to human and environmental receptors before they are approved for use. In postmarket regulation, chemicals are evaluated after they have been used and released into the environment.

Several EECs already are subject to premarket regulation. The U.S. Environmental Protection Agency (EPA) regulates chemicals that are classified as pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act and other chemicals under the Toxic Substances Control Act. These statutes require the manufacturer to provide information on the fate and effects of chemicals, thereby allowing EPA to perform a risk assessment that determines how a product may be used. Drugs are regulated under the Federal Food, Drug, and Cosmetic Act, administered by the U.S. Food and Drug Administration (FDA). FDA approval of a new drug is considered a major federal action significantly affecting the environment, and thus the provisions of the National Environmental Policy Act are triggered, requiring preparation of an environmental assessment, which evaluates the fate and effect of any new drug to the environment. However, FDA policy includes a provision for a drug's approval without an environmental assessment if the drug concentration is less than 1 µg/L.

The approach differs in Europe, where a tiered environmental risk assessment scheme has been proposed. The first tier consists of deriving a rough estimate of the predicted environmental concentration of a human pharmaceutical, based on predicted amounts used and specific removal rates in wastewater treatment or surface water. If this crude concentration is less than 0.01 µg/L and no environmental concerns are apparent, no further risk assessment is required. A tiered approach also has been developed in the European Union for veterinary medicinal products that considers the predicted environmental concentration in soil, surface water, and groundwater. Recently, Canada has implemented new requirements for ecological assessments of all new products regulated under its Food and Drugs Act.

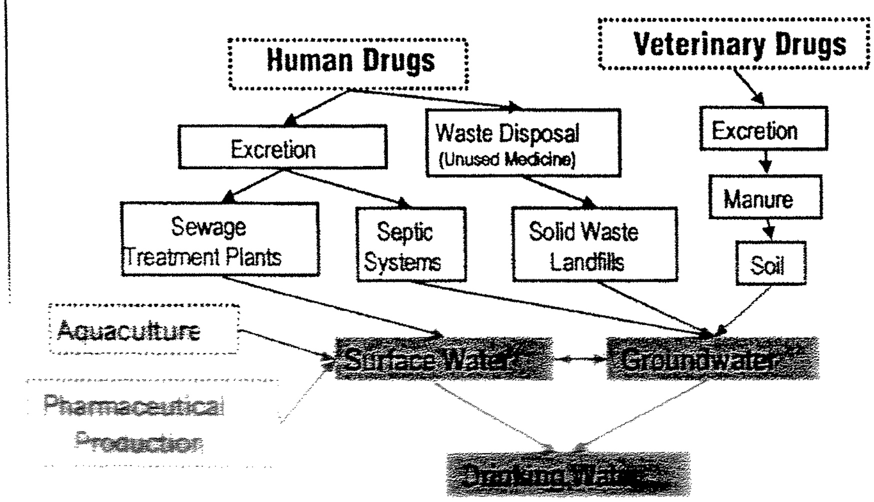
A significant shortcoming of existing approaches to assessing the environmental risks of EECs is that cumulative effects of contaminants affecting similar receptors are not considered. Consideration of cumulative effects is further complicated when chemicals have multiple uses and sources that fall under different regulatory programs. For instance, the antimicrobial compound triclosan is widely used in consumer and personal care products and is regulated by both FDA and EPA. However, at present, each agency evaluates triclosan independently, and thus the totality of sources, uses, and exposures in U.S. surface waters is not being assessed.

The specific provisions of current laws as well as differing agency policies and practices have led to a varying degree of premarket evaluation and regulation of EECs to date. Premarket risk assessments do not account for cumulative exposure and the risks of chemicals regulated by different statutes and agencies. Drugs and other FDA-regulated chemicals may be categorically excluded from an environmental risk assessment but may still contribute to cumulative exposure and risk. And after receiving initial regulatory approval, products receive typically little or no quantitative reassessment of exposure and risk (pesticides are the exception).

Need for More Postmarket Regulation

In the United States, once chemicals are present in surface water or groundwater, they are regulated under the Safe Drinking Water Act (SDWA) and Clean Water Act (CWA). Regulation under SDWA requires sufficient data to demonstrate that a contaminant is known or likely to occur at levels that may adversely affect human health and that regulating the contaminant will provide meaningful improvement to public health. Under CWA, states are required to establish water quality standards based on ambient water quality criteria, or the amount of a chemical that can be present and still allow the waterbody to support its designated

Figure 1
Sources and pathways of emerging environmental contaminants into the environment



uses. EPA has developed such criteria for a list of priority pollutants, but this list does not include most EECs.

Obviously, several regulatory issues must be addressed in the postmarket environment. The first question that should be asked is whether there are risks to human health or aquatic life that should be addressed through SDWA and CWA. There is a strong need for new analytical methods, sensitive ecological effects test methods, and environmental fate data, all of which preclude effective regulation at the present time.

Mary E. Sadler, P.E., is a process engineer in the Atlanta office of ARCADIS (Denver), and Jane P. Staveley is a principal environmental scientist in the Durham, N.C., office of ARCADIS.

Ethics at the Bench *continued from p. 1*

Certification (Ames, Iowa). This code states that "water and wastewater operators and analysts must protect the public health and the environment by utilizing their knowledge, skill, and judgment to ensure safe and effective utility operation. To successfully achieve this goal an operator or analyst will:

- Comply with all applicable state, provincial, and federal laws and regulations.
- Upgrade and maintain the knowledge and skills necessary to properly perform the duties of an operator or analyst.
- Conduct all professional duties with integrity and the highest possible ethical standards."

Other ethics codes are more complex. The American Council of Independent Laboratories (ACIL; Washington, D.C.), for example, has developed an Environmental Laboratory Data Integrity Initiative (ELDII) that ACIL literature describes as requiring "a systems approach to ensuring that data is of known and documented quality." ACIL's 16-page policy statement on ELDII calls for such elements as a business ethics and data integrity policy, an ethics and compliance officer, a policy on enforcing business ethics and data integrity through disciplinary action, a mechanism for anonymously reporting alleged misconduct, and a means for internally investigating such reports.

Meanwhile, to help labs establish and maintain the best practices, the U.S. Environmental Protection Agency (EPA) maintains a specialized Web site — www.epa.gov/quality/bestlabs.html — that lists links to references, training, examples, and other online resources on best practices for laboratory quality systems.

Finding the Source

Are ethics codes necessary, or will basic data integrity and data quality guidelines catch most errors?

"There are always a small group of individuals that are bound and determined to cheat," said Jack Farrell, president and CEO of Analytical Excellence Inc. (Altamonte Springs, Fla.), a consulting firm specializing in laboratory ethics. "You know there's not a whole lot you can do about that except put practices in place to spot it early and handle it early."

Data integrity problems arise from several sources, such as management failures, quality system failures, inadequate training, individual laziness or ignorance, and greed — "essentially, cutting corners," Farrell said. Such corner-cutting typically involves data that have been manipulated to bypass a quality control requirement, he said. Manual integration of organics data is probably most notorious, but it happens in all lab areas and types of analyses, he noted.

"You're never going to be able to prevent these types of events from occurring," Farrell said, "but if you put a good, strong data integrity system — which is similar to a quality system — in place that promotes prevention, communication, and ethical decision-making, you have a better chance of minimizing these occurrences." When problems arise, he said, they can be handled by lower-level analysts and supervisors — a process called "ethics at the bench."

Fostering Trust

Part of Farrell's business is teaching classes for lab personnel that combine ethics theory with practical group exercises. For example, a group may be asked to create a statement of organizational values. Defining organizational values clearly and publicly can help an analyst make decisions, Farrell said, because when an ethical dilemma arises, the employee will know which factor — such as honesty or productivity — is most important.

Everyone needs to know how the reporting system works, Farrell said, and "a culture of integrity promotes open communication, has defined procedures, and tends to promote ethics at the bench."

In the absence of such a culture, the reporting system can break down, as may have been the case at the District of Columbia's Water and Sewer Authority (WASA) during the last few years. According to numerous press reports, an analyst allegedly told superiors that lead contamination levels exceeded federal drinking water limits long before the utility district took any remedial action or informed the public. When the analyst allegedly deserted WASA's reporting chain by reporting the elevated lead levels directly to EPA, she was fired and then sued the utility district, press reports said.

WASA lawyers, however, alleged that

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Water Division Region IX - EPA 909-F-98-001

WATER RECYCLING AND REUSE: THE ENVIRONMENTAL BENEFITS

"Water recycling is a critical element for managing our water resources. Through water conservation and water recycling, we can meet environmental needs and still have sustainable development and a viable economy."

—Felicia Marcus, Regional Administrator

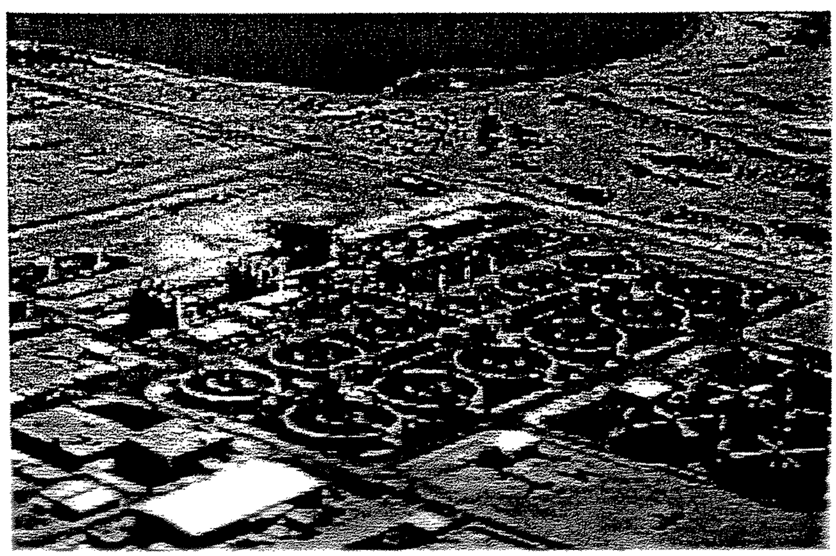
Front Cover—*The Experience at Koele Golf Course,* on the Island of Lanai, has used recycled water for irrigation since 1994. The pond shown is recycled water, as is all the water used to irrigate this world-class golf course in the state of Hawaii.

What Is Water Recycling?

Recycle: verb 1. a. To recover useful materials from garbage or waste.
b. To extract and reuse.

While recycling is a term generally applied to aluminum cans, glass bottles, and newspapers, water can be recycled as well. Water recycling is reusing treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin (referred to as ground water recharge). Water is sometimes recycled and reused onsite; for example, when an industrial facility recycles water used for cooling processes. A common type of recycled water is water that has been reclaimed from municipal wastewater, or sewage. The term water recycling is generally used synonymously with water reclamation and water reuse.

Through the natural water cycle, the earth has recycled and reused water for millions of years. Water recycling, though, generally refers to projects that use technology to speed up these natural processes. Water recycling is often characterized as "unplanned" or "planned." A common example of unplanned water recycling occurs when cities draw their water supplies from rivers, such as the Colorado River and the Mississippi River, that receive wastewater discharges upstream from those cities. Water from these rivers has been reused, treated, and piped into the water supply a number of times before the last downstream user withdraws the water. Planned projects are those that are developed with the goal of beneficially reusing a recycled water supply.



The Palo Verde Nuclear Generating Station, located near Phoenix, Arizona, uses recycled water for cooling purposes.

How Can Recycled Water Benefit Us?

Recycled water can satisfy most water demands, as long as it is adequately treated to ensure water quality appropriate for the use. Figure 1 shows types of treatment processes and suggested uses at each level of treatment. In uses where there is a greater chance of human exposure to the water, more treatment is required. As for any water source that is not properly treated, health problems could arise from drinking or being exposed to recycled water if it contains disease-causing organisms or other contaminants.

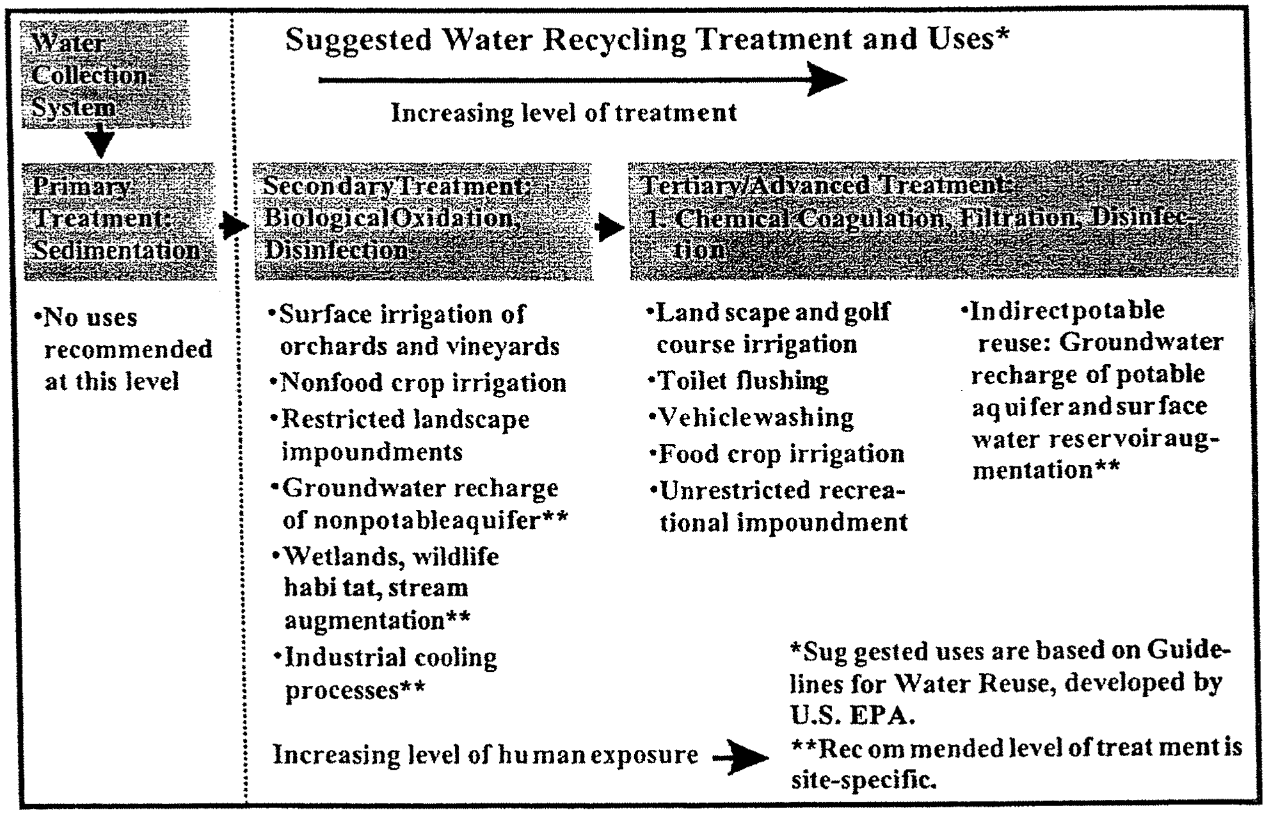
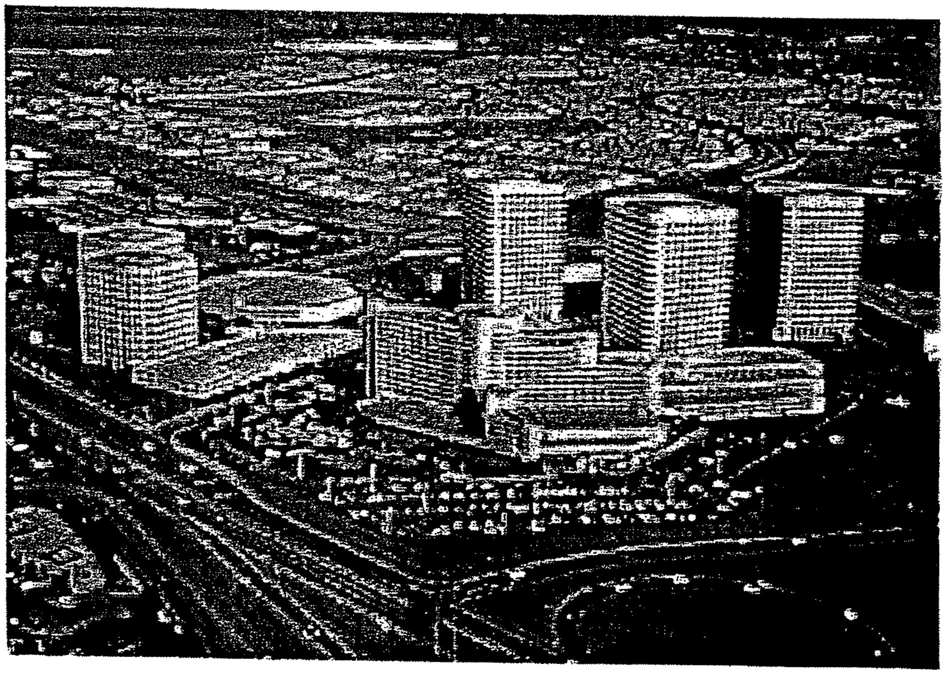


Figure 1: While there are some exceptions, wastewater in the United States is generally required to be treated to the secondary level. Some uses are recommended at this level, but many common uses of recycled water such as landscape irrigation generally require further treatment.

The US Environmental Protection Agency regulates many aspects of wastewater treatment and drinking water quality, and most states have established criteria or guidelines for the beneficial use of recycled water. In addition, in 1992, EPA developed a technical document entitled "Guidelines for Water Reuse," which contains such information as a summary of state requirements, and guidelines for the treatment and uses of recycled water. State and Federal regulatory oversight has successfully provided a framework to ensure the safety of the many water recycling projects that have been developed in the United States.



The Irvine Ranch Water District provides recycled water for toilet flushing in high rise buildings in Irvine, California. For new buildings over seven stories, the additional cost of providing a dual system added only 9% to the cost of plumbing.

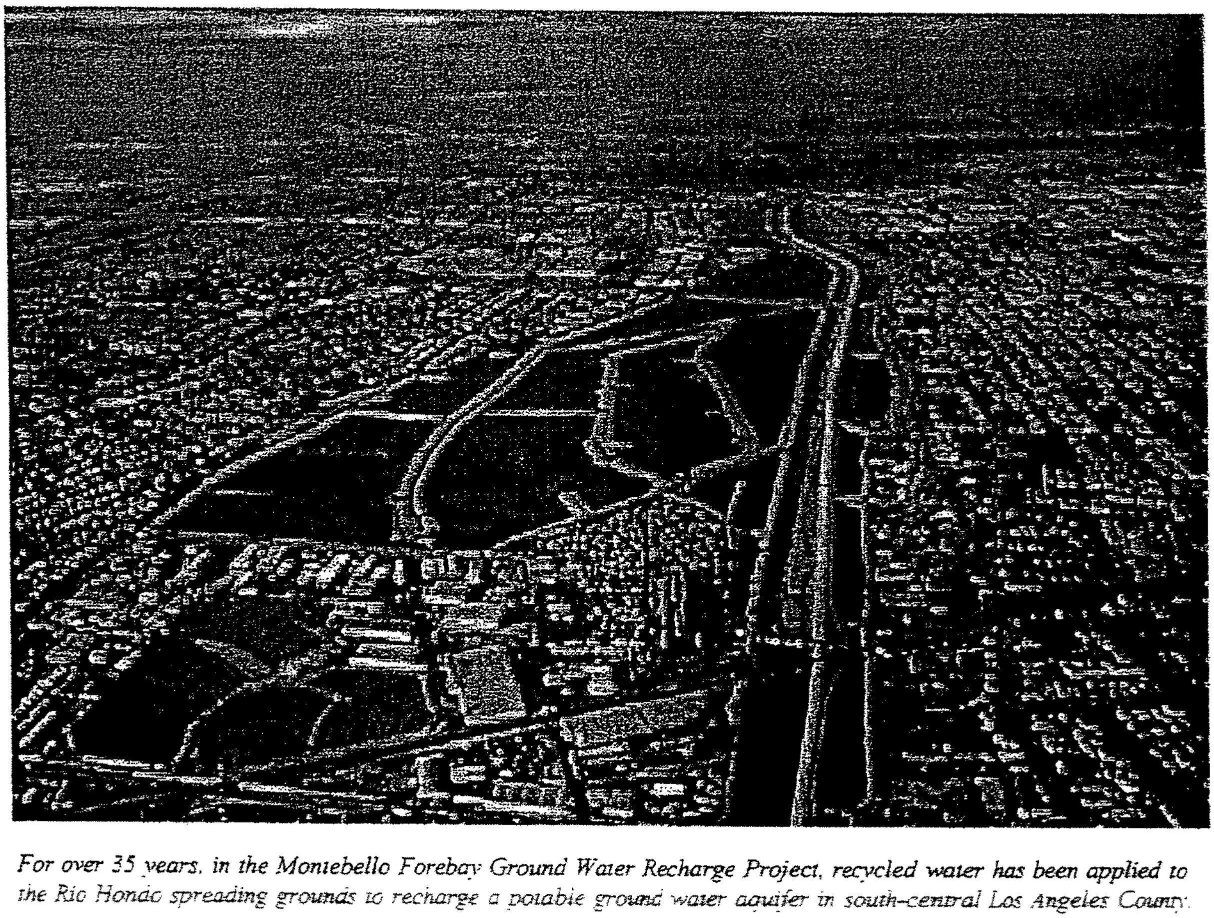
Recycled water is most commonly used for nonpotable (not for drinking) purposes, such as agriculture, landscape, public parks, and golf course irrigation. Other nonpotable applications include cooling water for power plants and oil refineries, industrial process water for such facilities as paper mills and carpet dyers, toilet flushing, dust control, construction activities, concrete mixing, and artificial lakes.

Although most water recycling projects have been developed to meet nonpotable water demands, a number of projects use recycled water indirectly[1] for potable purposes. These projects include recharging ground water aquifers and augmenting surface water reservoirs with recycled water. In ground water recharge projects, recycled water can be spread or injected into ground water aquifers to augment ground water supplies, and to prevent salt water intrusion in coastal areas.

[1] *Indirect potable reuse refers to projects that discharge recycled water to a water body before reuse. Direct potable reuse is the use of recycled water for drinking directly after treatment. While direct potable reuse has been safely used in Namibia, Africa, it is not a generally accepted practice in the United States.*

For example, since 1976, the Water Factory 21 Direct Injection Project, located in Orange County, California, has been injecting highly treated recycled water into the aquifer to prevent salt water intrusion, while augmenting the potable ground water supply.

While numerous successful ground water recharge projects have operated for many years, planned augmentation of surface water reservoirs has been less common. However, there are some existing projects and others in the planning stages. For example, since 1978, the upper Occoquan Sewage Authority has been discharging recycled water into a stream above Occoquan Reservoir, a potable water supply source



For over 35 years, in the Montebello Forebay Ground Water Recharge Project, recycled water has been applied to the Rio Hondo spreading grounds to recharge a potable ground water aquifer in south-central Los Angeles County.

for Fairfax County, Virginia. In San Diego, California, the Water Repurification Project is currently being planned to augment a drinking water reservoir with 20,000 acre-feet per year of advanced treated recycled water.

What are the Environmental Benefits of Water Recycling?

In addition to providing a dependable, locally-controlled water supply, water recycling provides tremendous environmental benefits. By providing an additional source of water, water recycling can help us find ways to decrease the diversion of water from sensitive ecosystems. Other benefits include decreasing wastewater discharges and reducing and preventing pollution. Recycled water can also be used to create or enhance wetlands and riparian habitats.

Water recycling can decrease diversion of freshwater from sensitive ecosystems.

Plants, wildlife, and fish depend on sufficient water flows to their habitats to live and reproduce. The lack of adequate flow, as a result of diversion for agricultural, urban, and industrial purposes, can cause deterioration of water quality and ecosystem health. Water users can supplement their demands by using recycled water, which can free considerable amounts of water for the environment and increase flows to vital ecosystems.

In California, Mono Lake's water quality and natural resources were progressively declining from lack of stream flow. In 1994, the Los Angeles Department of Water and Power was required to stop diverting one-fifth of the water it historically exported from the basin. The [illegible]

Water recycling decreases discharge to sensitive water bodies.

In some cases, the impetus for water recycling comes not from a water supply need, but from a need to eliminate or decrease wastewater discharge to the ocean, an estuary, or a stream.

For example, high volumes of treated wastewater discharged from the San Jose/Santa Clara Water Pollution Control Plant into the south San Francisco Bay threatened the area's natural salt water marsh. In response, a $140 million recycling project was completed in 1997. The South Bay Water Recycling Program

Incline Village, Nevada, uses a constructed wetland to dispose of wastewater effluent, expand the existing wetland habitat for wildlife, and provide an educational experience for visitors.

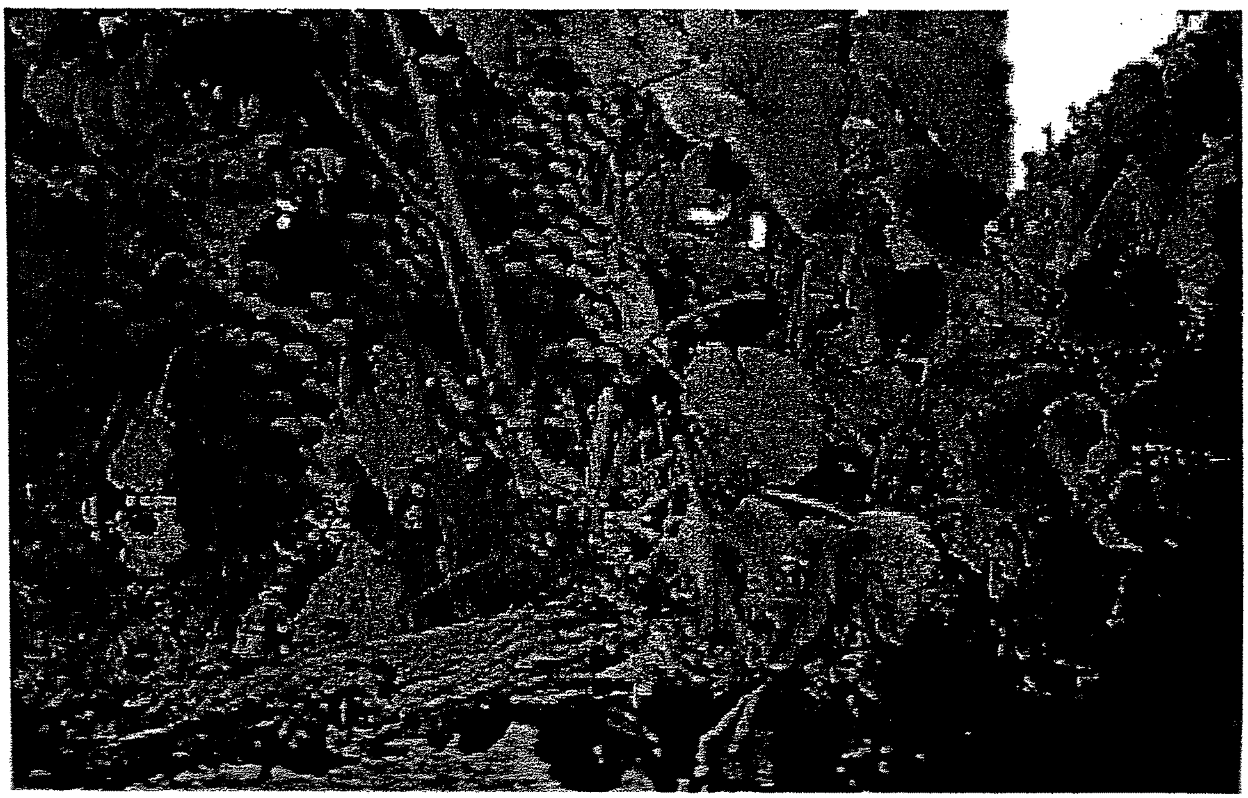
has the capacity to provide 21 million gallons per day of recycled water for use in irrigation and industry. By avoiding the conversion of salt water marsh to brackish marsh, the habitat for two endangered species can be protected.

Recycled water may be used to create or enhance wetlands and riparian (stream) habitats.

Wetlands provide many benefits which include wildlife and wildfowl habitat, water quality improvement, flood diminishment, and fisheries breeding grounds. For streams that have been impaired or dried from water diversion, water flow can be augmented with recycled water to sustain and improve the aquatic and wildlife habitat.

Water recycling can reduce and prevent pollution.

When pollutant discharges to oceans, rivers, and other water bodies are curtailed, the pollutant loadings to these bodies are decreased. Moreover, in some cases, substances that can be pollutants when discharged to a body of water can be beneficially reused for irrigation. For example, recycled water may contain higher levels of nutrients, such as nitrogen, than potable water. Application of recycled water for agricultural and landscape irrigation can provide an additional source of nutrients and lessen the need to apply synthetic fertilizers.



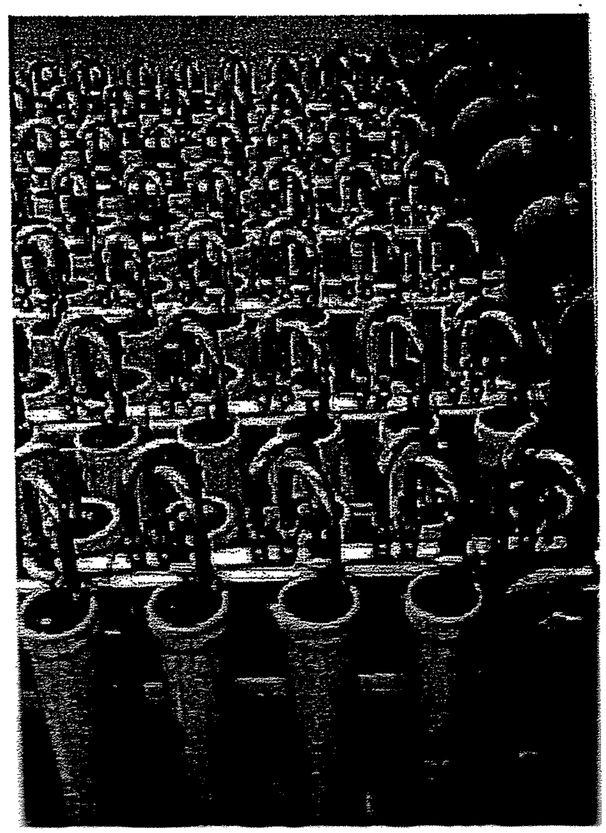
Recycled water has been used for a number of years to irrigate vineyards at California wineries, and this use is growing. Recently, Gallo Wineries and the City of Santa Rosa completed facilities for the irrigation of 150 acres of vineyards with recycled water from the Santa Rosa Subregional Water Reclamation System.

What Is The Future Of Water Recycling?

Water recycling has proven to be effective and successful in creating a new and reliable water supply, while not compromising public health. Nonpotable reuse is a widely accepted practice that will continue to grow. However, in many parts of the United States, the uses of recycled water are expanding in order to accommodate the needs of the environment and growing water supply demands. Advances in wastewater treatment technology and health studies of indirect potable reuse have led many to predict that planned indirect potable reuse will soon become more common.

While water recycling is a sustainable approach and can be cost-effective in the long term, the treatment of wastewater for reuse and the installation of distribution systems can be initially expensive compared to such water supply alternatives as imported water or ground water. Institutional barriers, as well as varying agency priorities, can make it difficult to implement water recycling projects. Finally, early in the planning process, agencies must implement public outreach to address any concerns and to keep the public involved in the planning process.

As water demands and environmental needs grow, water recycling will play a greater role in our overall water supply. By working together to overcome obstacles, water recycling, along with water conservation, can help us to conserve and sustainably manage our vital water resources.



At West Basin Wastewater Treatment Plant in California, reverse osmosis, an advanced treatment process, is used to [illegible]

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Video, entitled *Water from Water: Recycling,* produced in 1995 by National Water Research Institute, Fountain Valley, California.

Video, entitled, *Water in an Endless Loop,* produced in 1997 by WateReuse Foundation, Sacramento, California.

IMPLEMENTING SUSTAINABILITY IN WATER RECYCLING

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ABSTRACT

Applying sustainability as one of the decision criteria for evaluating projects is not only the right thing to do for reducing environmental impact, but also for determining long term economic viability. This paper will discuss the tools used for incorporating sustainability into water recycling facilities and will present two case studies, where these tools have been applied: Petaluma, California, and King County, Washington.

KEY WORDS

Sustainability, Water Reuse, Water Recycling, Ecological Footprint, The Natural Step™, LEED™

INTRODUCTION

In planning for wastewater recycling facilities, we have used two tools, The Natural Step Framework and the Ecological Footprint, to evaluate the relative ecological sustainability of various treatment alternatives. The Natural Step™ is a framework for evaluating sustainability. The Ecological Footprint measures the amount of bioproductive space required to produce all materials and energy consumed, and to sequester or absorb all wastes produced, for a given activity or to support a given population. The Ecological Footprint calculation allows easier direct comparison of sustainability criteria using a common unit system (acres).

During the pre-design and design phase, we have used the LEED™ Rating System to help develop environmental goals for projects and identify a multitude of strategies to meet those goals. The Leadership in Energy and Environmental Design (LEED™) Green Building Rating System is a performance-based certification system for buildings that demonstrate significant improvements in environmental performance beyond baseline standards.

DISCUSSION

Case Study 1:

The City of Petaluma, CA has embarked upon a project to replace their existing wastewater plant built in 1938 with a new water recycling facility. Citizens of Petaluma have a strong interest in being environmentally friendly. Consequently, one of the primary goals of the project is to design and build an ecologically and economically sustainable facility. The project team has incorporated sustainability criteria into the evaluation of alternatives, planning of the facility, and for design and construction. The Natural Step was used to establish project goals for sustainability. The Ecological Footprint was used to evaluated five different treatment trains for the whole plant (see attached figure) and to evaluate individual process decisions such as the use of UV versus chlorine for disinfection. The LEED™ Rating System was used to establish goals for design for the whole plant as well as the occupied buildings.

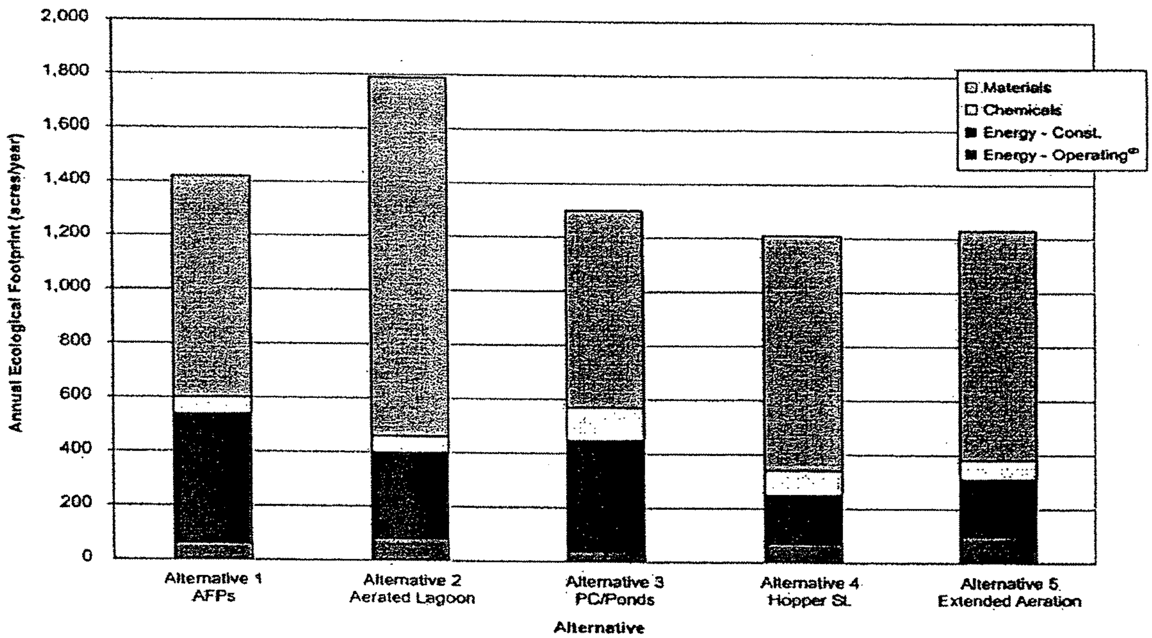
The City of Petaluma is located in California in the northern portion of the San Francisco Bay. The City currently provides wastewater treatment for approximately 55,000 residents. The treatment facilities are located in two places, downtown and east of town, outside the City limits. The City's facilities located downtown at Hopper Street were originally constructed in 1938 and upgraded in the 1950s and 1960s. The City also has 172 acres of oxidation ponds located out of town on Lakeville Highway, built in 1972. The Hopper Street facilities provide primary treatment for up to 6 mgd of flow, and secondary treatment (using two parallel trains, one aeration basins and one rock filters) for up to 4 mgd. Raw wastewater in excess of 6 mgd mixes with the primary and secondary effluent and is pumped out to the oxidation ponds for additional treatment. Final discharge is to the Petaluma River from October 21 - April 30 or to agricultural users from May 1 to October 20 (during non-discharge season). The ponds provide important storage during the non-discharge season, even though they also produce algae, which make meeting TSS requirements difficult at certain times of the year.

The facilities at Hopper Street are nearing the end of their useful life and need to be replaced. The city also wishes to develop recycling facilities for urban reuse which requires filtration and disinfection to meet California Department of Health Services Title 22 unrestricted reuse requirements. Other project goals included developing an economically and ecologically sustainable facility, and developing a facility that would serve as an amenity to the community by providing educational and recreational opportunities.

The City of Petaluma started their project to build a new recycling facility with a planning study to evaluate alternatives for treatment. At the kickoff meeting, The Natural Step framework was reviewed and project goals related to sustainability were established. The next step was to determine the criteria to be used for comparing alternatives. Criteria were grouped into the following categories: costs, neighborhood quality, wastewater treatment, sustainability and environment, and community amenities. Each category had several criteria and no category was given a greater weight than others were. These criteria were developed in part by input from citizens and City council members.

Alternatives were identified and screened in a brainstorming workshop with experts in pond systems, wetland systems, and conventional systems. Five alternatives were selected to be evaluated in further detail. The alternatives ranged from conventional activated sludge to natural/land based systems such as advanced facultative ponds and aerated lagoons. While most of the facilities at Hopper Street need to be abandoned, building new facilities on the Hopper Street site was evaluated as one alternative. All other alternatives considered locating the new facilities at, or adjacent to the existing oxidation ponds at the Lakeville highway site, which would be further from [illegible] receptors. For each alternative the oxidation ponds remained in the treatment train due to their [illegible] importance in providing storage in the non-discharge reuse season. However, since the ponds were included in each alternative, each alternative also included algae removal. The two sub-alternatives for algae removal were either dissolved air flotation (DAFs) or vegetated treatment wetlands. Each alternative also had a sub-alternative of using chlorine or ultraviolet light for disinfection for the unrestricted reuse.

After evaluating the alternatives for all the criteria established, the main difference between alternatives came down to costs and sustainability (as measured by ecological footprint). The ecological footprints for each alternative is shown in the following figure.



(1) Assuming UV Disinfection
(2) Assuming continued use of Calpine power (green power source)

Extended aeration was selected as the preferred alternative. This process actually had the second highest cost, but low environmental impacts (as measured by ecological footprint) and is a reliable process. Vegetated treatment wetlands were selected as the algae removal process following the ponds instead of DAFs, due to low energy use (sustainability). The ecological footprint evaluation for the UV verses chlorine showed that UV is more sustainable, especially when a green power source is used.

After completion of the planning study, design began. The secondary facilities are designed for an annual average flow of 8 mgd. Up to 4 mgd of the secondary effluent can be treated with filtration and UV for urban reuse. The remainder of the flow is sent to the oxidation ponds. Existing plant data shows that the oxidation ponds significantly reduce metals concentrations in the plant effluent. Therefore, all water discharged to the Petaluma River will first go through the existing ponds. The last two oxidation ponds will be converted to vegetated wetlands, totaling approximately [illegible] acres. An additional [illegible] acres of wetlands (open water and dense vegetation) will be created on land adjacent to the oxidation ponds for additional polishing of metals and nutrients. Disinfection for river discharge and the existing agricultural reuse program will continue to be provided by existing hypochlorite facilities located on the pond site.

Sustainable strategies that were evaluated in predesign and being used in final design include use of: high volume fly ash concrete; "green" or vegetated roofs; native plants for landscaping; waterless urinals; high efficiency lighting and appliances; and passive HVAC systems. Other strategies included are: minimizing site work required for construction; optimizing pump station design; and specifying that the contractor recycle construction and demolition debris. The operations and maintenance building is designed to meet LEED™ certification.

Case Study 2:

King County, Washington has plans to construct a new Reclaimed Water Production Facility (RWPF) in the Sammamish Valley. One of the project objectives is that the facility be a model for sustainable design. To help meet this objective, the relative ecological impacts of various treatment options were evaluated, along with a separate study of how the facility affects the sustainability of the overall region. Carollo used the Ecological Footprint to measure the relative ecological impacts of decisions affecting the Sammamish RWPF. The evaluation to answer the question of "Does this recycling project increase the sustainability of the region?" showed that there are multiple benefits of water recycling that are not included in a simple cost analysis. Sustainability allows evaluation of the true costs verses benefits.

In parts of the arid west, water reuse is driven by water supply issues, with not enough potable water to meet all the demands. In the relatively wet areas of the Pacific Northwest, most people would not expect water shortages to be an issue. However, water reuse is becoming more important in these areas because recent drought years have increased the need for maintaining critical water supplies for environmental protection.

Depending upon state regulatory requirements, water reuse may or may not be feasible based purely on cost, as treatment for water reuse (to be protective of public health) is generally required to be at a higher level than is required for river discharge. Due to the higher level of treatment, potable water costs are generally cheaper than the cost to treat wastewater for reuse. So why would an agency implement reuse? The answer lies in evaluating more than just the costs of a project. The benefits of reuse can be numerous and vary depending on the project, but typically include: improved water quality, alternative water supply, environmental enhancement (due to higher quality and increased stream flows), reduced discharge to receiving water bodies, and improved public perception of environmental stewardship. The key for decision makers is understanding community project drivers and including the appropriate benefits when considering a reuse project. The problem with such broad and comprehensive comparisons, of course, is the difficulty associated with making a true "apples to apples" comparison of various options. Placing a monetary value on the benefits of the project and comparing this value to the cost of the project is difficult at best. For a reuse project in the Sammamish Valley, Washington, Carollo Engineers and King County applied a method for comparing costs and benefits called the Ecological Footprint, which allows for an equitable determination of true project value

In planning the Sammamish Valley [illegible] Carollo and the County selected the most effective treatment processes to ensure a high quality product for both protection of public health and water quality. The treatment process selected was a membrane bioreactor (nitrification and denitrification in an extended aeration tank followed by microfiltration) and disinfection with ultraviolet light. These processes ensure a product with low nitrogen levels, little or no particles (solids), significant metals reduction, minimal disinfection by-products (DBPs) and full virus and bacteria inactivation.

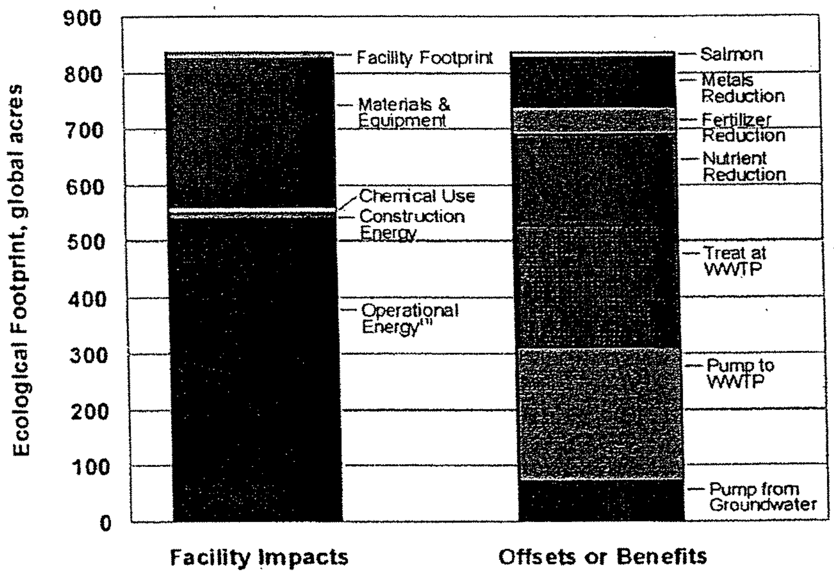
King County has a goal of implementing reuse in satellite locations. The Sammamish Valley was one such ideal location. The Sammamish Valley is a rural area to the east of Seattle, with significant agricultural resources. Water users identified for possible wastewater reuse rely on water pumped from the Sammamish River or from the groundwater. The Sammamish River runs out of Lake Sammamish through the Sammamish Valley and into Lake Washington. The Sammamish River supports important salmon runs of endangered Chinook salmon. Unfortunately, the Sammamish River faces low summer flows and poor dry weather water quality (impairment for dissolved oxygen, temperature and pH), particularly during critical late summer and early fall during the salmon runs. Reuse in the valley would provide water sources to offset groundwater and river pumping, thereby allowing more flow to remain in the river, and enhancing fish runs.

King County had several goals for the Sammamish Valley Reclamation Facility: keep more water in the river to enhance fish runs, preserve the rural character of valley, provide an alternate, reliable supply of high quality water, and provide a facility that serves as a model for sustainable design. To achieve the sustainable design goal, green building techniques were planned and an evaluation of the overall sustainability of the project was initiated. The sustainability was evaluated using the Ecological Footprint method. The Ecological Footprint is a calculation of the amount of land required to produce all the materials consumed in the construction and operation of a facility over its life, plus the land required to sequester or absorb all the wastes produced. It essentially represents the costs of the project in terms of environmental impact. To do an "apples to apples" comparison of the costs versus the benefits of the project, the ecological footprint was calculated for both the costs (construction materials, energy to construct, operating energy, and chemicals to operate) and the benefits.

The benefits of the project were considered as offsets of what the ecological footprint would be if the project were not constructed. Benefits (offsets) include: 1) the energy to pump the groundwater or river water that would be avoided, 2) the energy to pump the wastewater to the regional treatment plant that would be avoided (nearest regional plant over 20 miles away), 3) the energy to treat the wastewater at the regional facility, 4) the water quality improvements of not discharging nutrients to the receiving water (the regional plants do not nitrify), 5) offsetting the need for applied fertilizer to the reuse lands due to the nitrogen in the reuse water, 6) water quality improvement by decreasing metals released to the receiving water, 7) improvements to the salmon run, and 8) preservation of agriculture by providing a reliable water source which may help alleviate development pressures. The ecological footprints of the project costs versus benefits are shown in the attached bar graph.

The results of the evaluation show that the benefits or offsets, not including the agricultural preservation, are approximately equivalent to the ecological footprint of the impacts or costs of building and operating the facility. This assumes that a conventional Washington power mix

(Hydro, natural gas and coal) is used to operate the facility. If King County secures a contract with a green power supplier (from wind or solar), as they expect, the total ecological footprint for the facility drops by over 500 global acres and the benefits then exceed the impacts. Over 300 acres of agriculture would be supplied with reuse water from the facility, in addition to parks, soccer fields, a nursery, a winery and a golf course. Supplying a reliable source of water to the agriculture may help keep these farmers in business and help with the goal of agricultural preservation. When this is placed on top of the other considerations, the benefits of reuse in the Sammamish Valley definitely out weigh the costs.



(1) Assuming conventional WA power mix. King County is interested in pursuing green power supply which drops EF of operational energy to 17 global acres

CONCLUSIONS

In the wastewater and reuse field, the most common decision criteria used to evaluate alternatives in costs. However, to do a fair comparison, other criteria such as environmental impacts, public impacts and benefits and overall sustainability should also be used in the decision making process. The use of sustainability tools such as The Natural Step™, Ecological Footprint, and LEED™ can change the outcome of alternatives evaluation and change the way we think about and develop these projects.

ACKNOWLEGDEMENTS

Acknowledgements to Mathis Wackernagel and Redefining Progress for assistance in developing conversion factors for the Ecological Footprint

ıdirect Potable Reuse

or more than 50 years, California has been a pioneer in water recycling. Advances in technology and new philosophies about reventing the "waste" of water have combined to make water recycling an increasingly important part of water resources lanning. The next challenge is to expand the existing uses of recycled water to encompass potable reuse (drinking, cooking, and athing). Direct potable reuse – where the product water is released into a municipal distribution system immediately after eatment – is practiced only in Windhoeck, Namibia at this time and is probably far in the future in the U.S. However, indirect otable reuse is more widely practiced and becoming more accepted. The following paragraphs provide an overview of the rinciples involving indirect potable reuse.

Nhat Is Indirect Potable Reuse?

Nith indirect potable reuse, a highly treated recycled water is returned to the natural environment (groundwater reservoir, storage eservoir, or stream) and mixes with other waters for an extended period of time. Then, the blended water is diverted to a water reatment plant for sedimentation, filtration and disinfection before it is distributed. The mixing and travel time through the natural environment provide several benefits: (1) sufficient time to assure that the treatment system has performed as designed, with no ailures, (2) opportunity for additional treatment through natural processes such as sunlight and filtration through soil, and (3) ncreased public confidence that the water source is safe. Unplanned indirect potable reuse is occurring in virtually every major iver system in the United States today.

top

What Technology Is Used to Treat Water for Potable Reuse?

Membrane treatment is the most advanced technology for removal of the tiniest particles – including small ions such as sodium and chloride – from the recycled water. The most common membrane process employed is reverse osmosis (RO). Under relatively high pressure, water is forced across the semi-permeable RO membranes in special vessels to produce nearly pure water. Impurities are collected in a separate brine stream for disposal.

top

How Proven Is Indirect Potable Reuse?

The Denver Water Board, with assistance from the U.S. Environmental Protection Agency, conducted an intensive study of potable reuse, using a one million gallon per day pilot plant for five years. Several combinations of treatment processes were tested, and potable water was produced and analyzed for nearly all known contaminants. In addition, feeding studies were performed on rats and mice. Over several generations, rats and mice were given recycled water concentrates, while similar control groups were given water concentrates from the snowmelt from the highest peaks of the Rocky Mountains. No significant health differences were found between the two groups

top

What Are Some Examples of Indirect Potable Reuse?

For more than 20 years, the Upper Occoquan Sewage Authority (UOSA) Regional Water Reclamation Plant has been discharging to the Occoquan Reservoir, a principal water supply source for approximately one million people in northern Virginia. Because of the plant's reliable, state-of-the-art performance and the high-quality water produced, regulatory authorities have endorsed UOSA plant expansion over the years to increase the safe yield of the reservoir. UOSA recycled water is now an integral part of the water supply plans for the Washington metropolitan area. Other major projects with proven track records are in Los Angeles County and Orange County, California, and in El Paso, Texas.

top

What Are the Regulatory Controls for Indirect Potable Reuse?

A basic regulatory structure for water recycling and reuse projects has been in place in California since 1969. However, projects involving indirect potable reuse were traditionally evaluated on a case-by-case basis, making it difficult to plan for this type of water recycling application. A breakthrough occurred in January 1996 when a regulatory framework for potable reuse was adopted by a Committee convened jointly by California's Department of Health Services and Department of Water Resources. Eighteen individuals, representing these Departments and major water supply and sanitation organizations, signed the framework. The framework establishes six criteria that must be met before a potable reuse project proceeds. With these "ground rules" in place, agencies will find it easier to evaluate the feasibility of implementing an indirect potable reuse project.

top

What Are Multiple Barriers?

One of the most important concepts contributing to the growing acceptance of indirect potable reuse is that of multiple barrier protection. While RO is the heart of a potable reuse process, several other treatment processes are normally added to provide as near a fail-safe system as humanly possible. Primary and secondary treatment, dual media filtration, chemical additions, disinfection, and pretreatment are provided prior to the RO step. Each of these treatment steps removes a certain portion of the initial concentration of microorganisms and pollutants in the water. Additional removal capabilities follow. This combined treatment capability not only adds up to an impressive cleansing power, but also act as back-ups to one another in case any step in the system fails to perform. Storage is also viewed as an important barrier to contaminants. In addition to multiple-treatment processes, multiple barrier protections also include source control programs (preventing introduction of pollutants at the source) and strict operations and maintenance procedures.

top
